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Calspan Advanced Technology Center
Buffalo, New York 14225

CALSPAN ON-SITE INVESTIGATION OF TWO COMPRESSED NATURAL GAS (CNG) CYLINDER RUPTURES
CALSPAN CASE NOS. 94-19 AND 94-20

VEHICLES - TWO 1992 GMC SIERRA 2500 PICKUP TRUCKS

LOCATIONS - **1994)**
1994)

Contract No. DTNH22-94-D-07058

Prepared for:

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National Highway Traffic Safety Administration
Washington, D.C. 20590

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On-site investigation of two CNG cylinder failures which occurred during refueling activities.

16. Abstract

Two 1992 GMC Sierra 2500 series pickup trucks retrofitted by Production Automotive Systems, Inc. (PAS) to run on compressed natural gas (CNG) experienced a failure of one of their undercarriage mounted fuel storage/supply CNG cylinders. In each case, the left outboard cylinder of the three undercarriage mounted cylinders ruptured during refueling activities. The first case occurred 1994 in to a vehicle owned by and The driver attached the fill hose and sat in the vehicle with his left leg resting on the ground while waiting for the CNG fast fill system to complete refueling. As the pump system began to slow down at a pump recorded gauge pressure of 21,720 kPa (3,150 psi), the cylinder ruptured. The rupture occurred along the bottom surface of the cylinder midway between the two mounting straps. The metallic liner and fiberglass overwrap fractured and projected outward striking the left frame rail. This resulted in the outward and upward displacement of the frame rail and cargo box side panel. The driver suffered multiple lacerations from imbedded fiberglass fragments of the lower leg from the shredded overwrap.

The second case occurred 1994 in to a vehicle owned by As in the case of the event, this vehicle was nearing the end of the refueling cycle at an estimated pressure of 19,310 kPa (2800 psi) when the same left outboard undercarriage mounted CNG cylinder ruptured. The location of the rupture occurred along the bottom surface midway between the fore and aft mounting straps. The location and appearance of the rupture visually appeared to be identical to the cylinder rupture in the case. The driver was sitting in the driver's seat with the door and windows closed. He suffered minor injuries and was treated and released from a local hospital.

The root cause of the failures as determined by in a 1994 draft report to PAS was the result of "stress corrosion" cracking of the fiberglass overwrap.

17. Key Words Compressed Natural Gas (CNG) cylinder rupture; Composite CNG cylinder (metallic liner with fiberglass overwrap); Service pressure - 24,820 kPa (3,600 psi); Burst pressure - 89,230 kPa (12,942 psi); Production Automotive Systems, Inc. (PAS)	*18. Distribution Statement* General Public

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COMPRESSED NATURAL GAS CYLINDER FAILURES
1992 GMC SIERRA 2500 SERIES PICKUP TRUCKS

SUMMARY

This summary focuses on two separate investigations of cylinder ruptures in compressed natural gas (CNG) powered vehicles. The involved vehicles were similar 1992 GMC Sierra 2500 series conventional pickup trucks that were post-manufacture altered by Production Automotive Systems, Inc. (PAS) of PAS altered a fleet of approximately 2500 gasoline powered GMC and Chevrolet pickup trucks to dedicated CNG powered vehicles and distributed the trucks to the General Services Administration (GSA) and numerous utility companies. The GSA reportedly purchased the largest single fleet of these CNG vehicles which totaled approximately 600 trucks. The utility company fleets ranged in size of approximately 50-75 vehicles and were primarily distributed throughout the Midwest and Southwest regions of the country. These dedicated CNG powered trucks were used primarily as service vehicles throughout the various fleets.

The altered vehicles were conventional three-quarter ton rated pickup trucks with a gross vehicle weight rating (GVWR) of 3,266 kg (7,200 lbs.). The trucks were equipped with a 5.7 liter (350 C.I.D.) V-8 engine and a four-speed automatic overdrive transmission with a 4x2 wheel drive configuration on a 334.0 cm (131.5") wheelbase. PAS received the trucks as complete vehicles directly from the assembly plant in The alteration from gasoline powered to CNG powered required the removal of the gasoline fuel tank and its delivery system and the installation of a specially designed CNG system. This alteration added approximately 68 kg (150 lbs.) to the original curb weight of the vehicle.

The PAS CNG alteration utilized a series of three composite cylinders that were mounted to the undercarriage of the vehicle between the frame rails. The cylinders were manufactured by Comdyne 1, Inc. and were classified as Type 3 pressure vessels which consisted of an extruded aluminum liner with a dual direction (longitudinal and lateral) fiberglass overwrap. The manufacturer's specifications listed the minimum sidewall thickness of the liner at 0.401 cm (0.158 ") with a nominal fiberglass wrap thickness of 1.067 cm (0.420 "). The cylinders had an outside diameter of 22.23 cm (8.75") and were 163.8 cm (64.5") in length (boss to boss) with a service pressure rating of 24,820 kPa [3600 pounds/in ^{2} (psi)]. The Comdyne representative stated that each cylinder was tested to 41,370 kPa (6,000 psi) prior to shipment and that every one hundredth cylinder manufactured was burst tested to ensure a high standard of safety. The virgin burst pressure of these composite cylinders was 3.6 times the rated service pressure of 24,820 kPa (3600 psi), or 89,230 kPa (12,942 psi). Each end of the CNG cylinder is formed with a boss which is threaded to accept a valve. The forward end of the cylinder, as positioned in the vehicle, was equipped with a hexagonal two-way electric solenoid valve that opens to permit fuel flow when the vehicle's ignition is turned to the on-position. The solenoid valve also closes the fuel system when the ignition is turned off to permit refueling of the CNG cylinders. A safety relief valve was positioned at the rear of each cylinder. This valve was designed to rapidly release the natural gas pressure of the cylinder whenever the gas is heated above 149° C (291° F) or when internal pressures exceed 1.5 times service pressure, or 37,230 kPa (5,400 psi).

The cylinders were mounted longitudinally to the mid cross members of the pickup trucks and were positioned between the frame rails in the area of the factory installed gasoline fuel tank. Two of the cylinders were positioned between the left frame rail and the drive shaft while the third cylinder was positioned between the drive shaft and the right frame rail, adjacent to the exhaust system. PAS modified the exhaust system for the CNG alteration by repositioning the muffler between the frame rails, rearward of the rear axle, and redirecting the exhaust pipe along the right frame rail and through the rear mounting bracket for the right CNG cylinder. The cylinders were mounted to 5.1 cm (2.0") wide formed steel brackets that were bolted to the cross members. The left side cylinders were secured to the brackets by common retaining straps that extended from the lower edge of the left frame rail to the inboard aspect of the center cylinder bracket. The third cylinder was retained by a separate bracket/strap system. A thin strip of rubber was positioned around each cylinder at the bracket/strap locations. The left cylinder was mounted adjacent to the lower inboard edge of the U-channel frame rail. As a step in the alteration process, PAS removed approximately 0.64 cm (0.25") of the left frame rail edge in the area of the forward leaf spring shackle bracket. A rubberized edge guard was positioned over the removed frame edge to prevent direct contact between the cylinder and the rail. [An inspection of four similar PAS altered vehicles revealed clearances of 0.00 mm - 0.36 mm (0.000" - 0.014") between the edge guard and the left outboard cylinder].

The longitudinally mounted cylinders were covered with a high density polyethylene (HDPE) shield that was attached to the bottom of each cylinder with three stainless steel straps to help protect the composite cylinders from impact damage. In addition to the HDPE shield, the right side cylinder was partially covered with a three-piece formed heat shield to reduce heat transfer from the exhaust system.

The cylinders were refueled through a one-way filler valve that was located within the conventional fuel door at the left quarter panel. The valve was plumbed into the fuel supply system by pre-formed armor covered seamless, stainless steel lines that connected to a four-way fitting. Armor covered stainless steel lines extended from the fitting to the electric solenoid valves on each of the three CNG cylinders. Separate fuel delivery lines extended from the solenoid valves to another four-way fitting that transferred the CNG to the fuel delivery system. A manual shut-off valve was located on the inboard edge of the left frame rail under the mid point of the passenger compartment area of the vehicle.

Refueling of the CNG system was accomplished by one of two methods available for this type of alternative fuel system. The most common method, and the method used at the time of these cylinder ruptures, involved a fast-fill type procedure. Natural gas is pumped into a cascading tank or tanks and is pressurized. The gas is subsequently transferred from the cascading tanks to the CNG cylinders by a pump. The outboard side of the pump is equipped with a quick-disconnect coupler in which a high pressure hose is attached. The vehicle side of the high pressure hose is equipped with a manual shut off valve and a quick-disconnect type coupler that attaches to the filler valve. With the hose in place, the operator turns on the pump which zero's out a pressure gauge on the pump and starts the flow of CNG to the vehicle. This fast-fill process requires slightly more time to refuel than a conventional gasoline system. The gauge on the pump records the refueling pressure and retains the reading after the pump has been turned-off.

The second refueling method involves a slow-fill process in which the vehicle is plumbed into a refueling line and is allowed to fill over an extended period of time. This method is usually performed at night when the vehicles are not in service.

The fuel filler door was equipped with a plunger type switch that is activated by the opening and closing of the filler door. With the door in the open position, the fuel door switch prevents the engine from being started during refueling and prevents the electric solenoid valves from passing fuel to the delivery system.

In addition to the three Comdyne cylinders located within the vehicle's frame, the involved pickup trucks were retrofitted by the utility companies with an additional auxiliary CNG cylinder mounted to the forward area of the cargo box. The cylinders were steel with a fiberglass hoop-wrap (lateral wrap) and were rated at 20,680 kPa (3,000 psi) service pressure. The auxiliary cylinders were mounted laterally across the bed and were retained by two steel brackets and straps that were bolted through the floor of the cargo bed. The auxiliary cylinders were plumbed directly into the PAS fuel line system and were refueled simultaneously with the Comdyne cylinders. A pressure gauge and manual shut-off valve were fitted into the plumbing configuration at the boss end of the tank on the left side of the vehicle. There were no protective covers over this assembly. The auxiliary cylinders provided additional mileage range to the vehicles. A detailed reference manual for the PAS CNG alteration to the GMC pickup trucks is included under Appendix C.

CALSPAN CASE NO. 94-19
1992 GMC SIERRA 2500 PICKUP TRUCK
CITY OF
1994

The first reported incident that involved a CNG cylinder rupture occurred in on 1994, during daylight morning hours. The involved pickup truck was owned and operated by the and The 1992 GMC Sierra pickup truck was manufactured on 92 and was identified by the following vehicle identification number (V.I.N.): IGTFC24K8 At the time of the cylinder rupture, the vehicle had an odometer reading of 13,964.2 km (8,677.2 miles). In addition to the PAS CNG alteration, the pickup truck was equipped with an anti-lock brake system (ABS), air conditioning, a frame mounted receiver type trailer hitch, a cargo bed liner, and a modified bed mounted tool box. The tool box was mounted laterally across the cargo bed of the truck at the forward end of the bed. The bottom of the box appeared to have been cut away to fit over the auxiliary CNG cylinder that was mounted in the bed.

The driver of the pickup truck was an employee of He reportedly drove the vehicle to a service facility to refuel the truck with CNG. representatives stated that company policy regarding refueling CNG vehicles requires that all employees must remove the ignition key from the switch prior to connecting to the pump. The driver exited the vehicle at the dedicated CNG refueling station and connected the pressure hose at a fast-fill station to the filler valve on the vehicle and turned the pump to the on-position to initiate the fueling process. He returned to the cab of the pickup truck and sat in the driver's position with his left leg extended out the left door opening and his foot resting on the asphalt parking lot surface. The driver reportedly heard the flow of the CNG slow down which was an indication that the system was nearly full. As he remained in the truck, the left outboard CNG cylinder ruptured at the bottom mid point of the pressure vessel. The fiberglass wrap around the cylinder shattered in a debris pattern that extended out from under the vehicle toward the 9 o'clock-10 o'clock direction. The fiberglass debris contacted and penetrated the lower left leg of the driver. He immediately exited the vehicle and turned the pump to the off-position. personnel investigated the incident, recorded the pump gauge pressure at 21,720 kPa (3,150 psi), 3,100 kPa (450 psi) below the rated service pressure of the cylinder.

The bottom left area of the left side composite cylinder ruptured between the mounting straps at the mid point of the cylinder. The aluminum liner fractured in a longitudinal direction in an H-configuration with the flaps opening toward the sides of the vehicle. The dual direction fiberglass wrap fractured at the rupture point and partially separated from the cylinder circumferentially. The left outboard flap of the aluminum liner and the fiberglass wrap contacted the lower edge of the left C-channel frame rail between the cross-members. The contact deformed the lower edge of the rail against the inboard vertical surface of the rail and displaced the rail approximately 6.4 cm (2.5") outward. The fiberglass wrap at the inboard edge of the ruptured cylinder contacted the center cylinder's HDPE shield. The contact deformed the shield and produced laterally orientated abrasions that extended from the midpoint to the left edge of the

shield and onto the cylinder. The HDPE shield remained intact and there was no significant damage to the fiberglass wrap of the center cylinder.

The rupture shattered the left cylinder's HDPE shield into nine separate pieces and completely separated the shield from the cylinder. The high pressure rupture of the left cylinder thrust the center area of the pressure vessel in an upward direction, thus displacing the ends of the cylinder downward. In addition, the cylinder probably rotated slightly in a clockwise direction (as viewed longitudinally from the front of the vehicle). The upward deflection of the midpoint of the cylinder stressed the common lower retaining straps for the left side cylinders. The center of the straps were cinched upward by a bolt/nut configuration which firmly secured the cylinders against the upper brackets. As a result, the tension nut pulled through the lower straps and released the tension on the straps. The fiberglass wrap and the top surface of the deformed cylinder contacted the underside of the cargo bed, which deformed the floor and unitized cross members of the bed. The thrust generated from the cylinder rupture and the debris from the fiberglass wrap deformed the lower forward edge of the left quarter panel in an outward direction. The area of deformation extended from the wheel opening to the leading edge of the bed. representatives stated that the rupture also displaced the aftermarket tool box from the bed of the truck. The tool box separated from its attachment points and came to rest upside down across the cargo bed.

At the time of this on-site investigation, the GMC pickup truck had been transported to an independent metallurgical laboratory. The vehicle was initially observed with the cargo box removed and the vehicle elevated on blocks. The right side CNG cylinder had been removed from the vehicle along with the HDPE shield and the shield from the center cylinder. The drive shaft was also removed from the vehicle. A 2.54 cm x 4.45 cm (1.00" x 1.75") triangular gouge was noted to the tail end of the aluminum drive shaft, directly forward of the yoke. The gouge probably resulted from a rebound type impact by a fragment of the aluminum cylinder liner.

The laboratory staff disconnected the plumbing from the solenoid valve of the left side cylinders and supported the cylinders with nylon straps attached to a bar that was placed across the top of the frame rails. The retaining straps were subsequently removed and the cylinders were carefully lowered from the vehicle. The ruptured cylinder was placed on saw horses for visual inspection and photographic documentation. The identification labels on the ruptured cylinders were placed at the front of the unit and were not damaged. The cylinder was identified by the following:

DOT-E10256-3600
1838 M4020
92 (Manufacture Date)

P/N 27501000AF 55
ASSY P/N 27501010AF-1
RETEST BURETTE SIZE 3,000 cc

WARNING:

Do not fill if cylinder has damage which has
caused unraveling of the composite fibers.

This high pressure cylinder must be reinspected
and hydrostatically retested in accordance with
U.S. Department of Transportation (DOT) regulations.

The rupture point on the aluminum liner appeared to have initiated in a longitudinal direction then radiated laterally as the flaps opened in an outward direction. Two large aluminum fragments separated from the cylinder at the rupture point and were recovered at the scene of the incident. The ruptured area of the cylinder was located between the mounting straps, forward of the center point of the cylinder. The opening created by the rupture was approximately 30.5 cm (12.0") in width by 27.9 cm (11.0") in length. The longitudinal strands of the fiberglass wrap appeared to be shredded in an irregular pattern across the rupture area while the inner layers of the lateral wrap appeared to have been cut in a uniform pattern from either the aluminum liner or from contact with the edge of the frame rail. The outer layers of the lateral wrap separated circumferentially in a band-like pattern. The fiberglass wrap over the ruptured area was fragmented into individual splinters and was scattered in a pattern that extended from the left side of the vehicle toward the 9 o'clock-10 o'clock direction.

initially retained possession of the ruptured cylinder and consulted with local experts in an attempt to identify the source of the rupture. When the root cause could not be determined, it was subsequently shipped to in for metallurgical and composite analysis. The outcome of their research and testing indicated the cylinder failed as the result of stress corrosion cracking of the fiberglass overwrap.

CALSPAN CASE NO. 94-20
1992 GMC SIERRA 2500 PICKUP TRUCKS
CITY OF CITY OF
1994

On 1994, a 1992 GMC Sierra, 2500 pickup truck owned by in which was equipped to operate on compressed natural gas (CNG) experienced a sudden rupture of one of the three undercarriage mounted CNG composite fuel cylinders. The subject cylinder was located in the same position as the failed cylinder in the case which was mounted adjacent to the left frame rail. The site of the rupture was located along the downward facing longitudinal surface of the left cylinder, midway between the fore and aft mounting straps. The vehicle's odometer indicated 17,958 km (11,159 miles). The vehicle was manufactured 1992 with the following VIN: 1GTFC24K0

Each mounting strap accommodated the left and center cylinder as a common mounting system. The outboard end of the strap was attached to the left frame rail and the inboard end anchored to a chassis cross member. A bolt located at the mid point of the strap was threaded through the strap and into the chassis cross member which simultaneously secured both cylinders to the mounting blocks. The center and right side CNG cylinders maintained vessel integrity during the rupture event.

During refueling, the driver was sitting in the driver's seat position with the left front door and window in the closed position. A witness waiting to refuel his vehicle reportedly observed the upward movement of the pickup truck following the CNG cylinder rupture cycle. The vehicle subsequently sustained damage to the left frame rail, frame cross members, the bed of the pickup cargo box, the drive shaft (dent), the left side panel of the cargo box, the left front door (lower surface), the left front door glazing (shattered), and the windshield glazing (induced stress cracks). The witness then exited his vehicle and activated the pump's emergency shut-off switch.

The driver of the subject vehicle contacted the headliner above the driver's seat with his head during the rupture sequence . Solid tempered side glazing fragments, tissue, and hair fibers were imbedded from this contact in the vinyl material. The driver was transported to the hospital where he was treated and released.

After officials from General Motors Corporation were notified by of the tank failure, the vehicle was wrapped in a protective covering and transported in an enclosed flatbed truck to the GM Technical Center in At the time of this inspection, the three undercarriage CNG cylinders, their respective HDPE shields, the right cylinder heat shield, and upper mounting brackets were already removed from the vehicle. The ruptured cylinder was resting in a make shift wooden cradle with the rupture area facing up (refer to photograph #38 on page B-20). The HDPE shields were arranged on the floor in a chronological order and oriented with respect to the front of the vehicle. Officials from GM were eager to have us join the investigation in attempting to determine the cause of the rupture. However, other concerned parties (primarily were initially reluctant which hampered a timely arrival. Plans

to transport the cylinders directly to by corporate jet for testing were temporarily delayed by this investigation. The GM officials (although eager to ship the cylinders as soon as possible) afforded us as much time as possible to inspect and document the cylinders. The remainder of the vehicle inspection was completed the following day.

The rupture pattern of the CNG cylinder resembled an "H" configuration with the crossbar of the "H" aligned longitudinally with respect to the length of the cylinder and the remaining segments of the "H" oriented circumferentially. The rupture pattern opened outward with the aluminum liner forming two lateral flaps (i.e. bomb bay door fashion). The rupture site occurred along the downward facing surface of the cylinder which resulted in an upward deflection of the cylinder near the longitudinal center of the cylinder. The deflection angle of the cylinder was calculated at approximately 16° at its resting position in the cradle following removal from the vehicle. The forward circumferential rupture point of the aluminum liner was located 56.5 cm (22.25") rearward of the cylinder's leading end as referenced to the junction of the fiberglass wrap with the boss. The fiberglass wrap along the forward circumferential fracture line was located 48.3 cm (19.0") rearward from the same reference point. The rearward circumferential rupture point of both the aluminum liner and fiberglass wrap was located 61.0 cm (24.0") forward of the rear of the cylinder as referenced to the junction of the fiberglass wrap and rear boss.

The fiberglass wrap in the area of the rupture appeared to have both a well defined blunt edge fracture pattern and an irregular pattern of shredded fiberglass strands. The blunt edge pattern appeared to be located over the site of the longitudinal aluminum liner rupture line. The shredded pattern appeared be oriented in a 90° opposed direction along the circumferential rupture line (refer to photographs #39, #40 on page B-21).

The left flap of the aluminum liner appeared to contact the vehicle's left frame rail during the fracture sequence resulting in a 5.1 cm (2.0") outward and 6.4 cm (2.5") upward displacement of the frame rail. The aluminum liner flap was observed during inspection to be irregularly shaped with at least two fragments separated from the cylinder (photographs #48-#51 on pages B-25-B-27 illustrate one of these fragments). The right flap exhibited a more symmetrical rupture pattern with a relatively straight edge configuration along the longitudinal edge. However, this edge appeared to be bevelled in opposite directions with the forward half of the flap bevelled inward and the rearward portion bevelled outward as shown in photograph #40 on page B-21.

The center of the protective HDPE shield which was attached to the bottom of the CNG cylinder by three stainless steel straps was shattered into six pieces during the rupture sequence. The HDPE shield over the adjacent center CNG cylinder exhibited fiberglass transfers from the right flap of the ruptured CNG cylinder. It also experienced a 2.5 cm x 1.3 cm (1.0" x 0.5") wide puncture near the longitudinal edge of the fiberglass transfer along the bottom of the shield.

The fuel lines (both supply and delivery) and fuel line fittings remained attached to the left CNG cylinder following the rupture sequence. There was evidence of fuel line bending which may have occurred from the downward pitching of the cylinder end in response to the upward movement of the cylinder's center section (refer to photograph #26 on page B-14). GM engineers were of the opinion the left cylinder rotated clockwise approximately 48^0 as viewed from the front

of the vehicle. Their determination was based on the relative position of the solenoid valve. We did not discover any evidence during our investigation to support the rotational theory.

The left and center cylinders (by design) shared common lower retaining straps where the outboard ends of the straps were secured directly to the left frame rail as seen in photographs #29, #30, and #37 on pages B-16, B-20. The inboard end of the straps were bolted to frame cross members. A center nut and bolt located in the center of the straps secured the cylinders against the overhead mounting brackets. When installed, the fiberglass strap flanges of both cylinders appeared to be in contact with each other as observed during the follow-on inspection of exemplar vehicles. During the rupture sequence, the center securing nut on both the forward and rear retaining straps pulled through the metal straps.

The left frame rail adjacent to the site of the CNG cylinder rupture was displaced outward and upward. Additionally, the lower frame rail edge in this area [approximately 36.8 cm (14.5") in length] rotated upward against the inside of the frame rail. This upward folded damage pattern was located 195.6 cm (77.0") forward of the rear left frame rail end. The total length of frame deformation was 93.7 cm (36.9") which began approximately 182.9 cm (72.0") forward of the left rear frame rail end and extended forward to 276.6 cm (108.9") from the rear frame rail end. The rear cylinder retaining strap of the left cylinder was located 171.2 cm (67.4") forward of the left rear frame rail end and the front strap was positioned 243.21 cm (95.75") forward of the of the same reference point. Within this area, the left spring shackle was attached by a shackle bolt to the outboard vertical side surface of the frame rail which was located 184.79 (72.75") forward of the left rear frame rail end.

The lower frame rail edge was modified by PAS to accommodate the left CNG cylinder. This modification was accomplished by removing a 38.74 cm (15.25") long narrow strip of the lower frame edge. The removal process created a serrated edge pattern (refer to photograph #35 on page B-19). This edge was reportedly covered by a rubberized edge guard which was recovered at the scene.

The manufacture information on the identification label of the ruptured cylinder was:

DOT-E10256-3600
902 M4020
92

P/N 27601000AF
ASS. P/N 27501010AF-1
RETEST BURETTE SIZE: 3,000 cc

The manufacture information on the identification label of the center cylinder was:

DOT-E10256-3600
1090 M4020
92

The three undercarriage mounted cylinders were equipped with safety relief valves mounted at the rear boss of each cylinder and reportedly designed to relieve pressures exceeding 1.5 times the service pressure or 37,230 kPa (5,400 psi). Each cylinder was also equipped with a service solenoid actuated fuel valve which accepted a separate supply and delivery line. The valves were intact at the time of inspection. However, the internal components of the left cylinder valve were expelled from the cylinder during the rupture sequence (refer to photograph #52 on page B-27). The hoop-wrap steel cylinder transversely mounted in the forward position of the cargo bed was not damaged during the rupture sequence although the bed was buckled upward in the area of the left mounting bracket.

CONCLUSION

The following theories have been discussed as the probable cause for the cylinder failures with representatives of General Motors, and .

- Vehicle frame load forces (longitudinal and torsional) transferred to the left undercarriage cylinder as the result of a rigid mounting system.
- Degradation of the fiberglass wrap due to moisture absorption or environmental agents such as salt spray or ultra violet contamination.
- Structural failure of the pressure vessel.

The research and testing conducted by favors the second probable cause as the leading candidate for pressure vessel failure. In a draft written report to PAS dated 1994, they concluded the failures were a result of stress corrosion cracking of the fiberglass overwrap brought on by exposure to an aggressive environment. However, this conclusion does not fully explain why the failure occurred to the same cylinder in both vehicles and why the damage outcome to both cylinders and vehicles appeared to be identical. It seems unlikely the subject cylinders were more exposed to an aggressive environment than the other four undercarriage cylinders.

Other theories for cylinder failures that were considered and have been ruled out include the following:

- Emergency brake cable contact with the CNG cylinder.
- Puncture/damage from road obstacles/hazards.

- Overpressurization of cylinder [> 37,230 kPa (5,400 psi)]

For a summary of similarities and dissimilarities of the two cylinder failures, refer to Table 1.

OUTCOME

As the result of these failures, General Motors Corporation issued a recall campaign on the entire fleet of the PAS CNG equipped pickup trucks where owners were offered a vehicle buy out or a vehicle replacement option. The vehicles were reportedly returned to where they were scheduled for reconversion to gasoline powered or salvaged. These events, at least for the short run, have halted the introduction of CNG powered vehicles which were planned for the 1995 model year.

Table 1.

Similarities and dissimilarities between cylinder rupture events with owned and Minnegasco owned CNG equipped vehicles

SIMILARITIES

1. PAS altered GMC Sierra pickup truck, 2500 series	1. PAS altered GMC Sierra pickup truck, 2500 series
2. Mileage A. 13,964 km (8,677 miles)	2. Mileage A. 17,958 m (11,159 miles)
3. Rupture occurred during fast-fill refueling activities A. 21,720 kPa (3,150 psi)	3. Rupture occurred during fast-fill refueling activities A. 19,310 kPa (2,800 psi)
4. Rupture of the left CNG cylinder mounted adjacent to the left frame rail	4. Rupture of the left CNG cylinder mounted adjacent to the left frame rail
5. Cylinder damage A. Symmetrical "H" pattern rupture B. Blunt shear pattern of fiberglass wrap along longitudinal line of rupture C. Rupture facing ground	5. Cylinder damage A. Symmetrical "H" pattern rupture B. Blunt shear pattern of fiberglass wrap along longitudinal line of rupture C. Rupture facing ground
6. Blow-out of internal components of solenoid valve	6. Blow-out of internal components of solenoid valve
7. Vehicle frame and body damage	7. Vehicle frame and body damage
8. Add-on hoop-wrapped CNG steel cylinder in cargo box	8. Add-on hoop-wrapped CNG steel cylinder in cargo box
9. Undercoat overspray on CNG cylinders	9. Undercoat overspray on CNG cylinders
10. Environmental salt conditions A. Ocean spray	10. Environmental salt conditions A. Road spray

DISSIMILARITIES

1. Environmental temperature A. 16^{0}+ C (60°+ F)	1. Environmental temperature A. $<$-18^{0}C (Subzero degrees F)

APPENDIX A

Selected Prints

Calspan Case 94-19

Selected Prints

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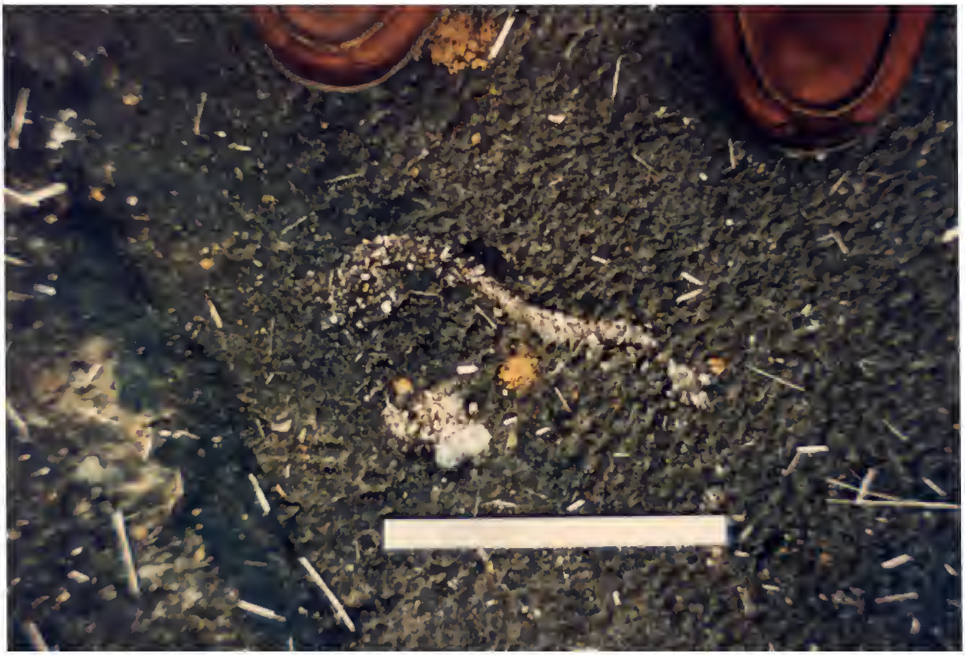

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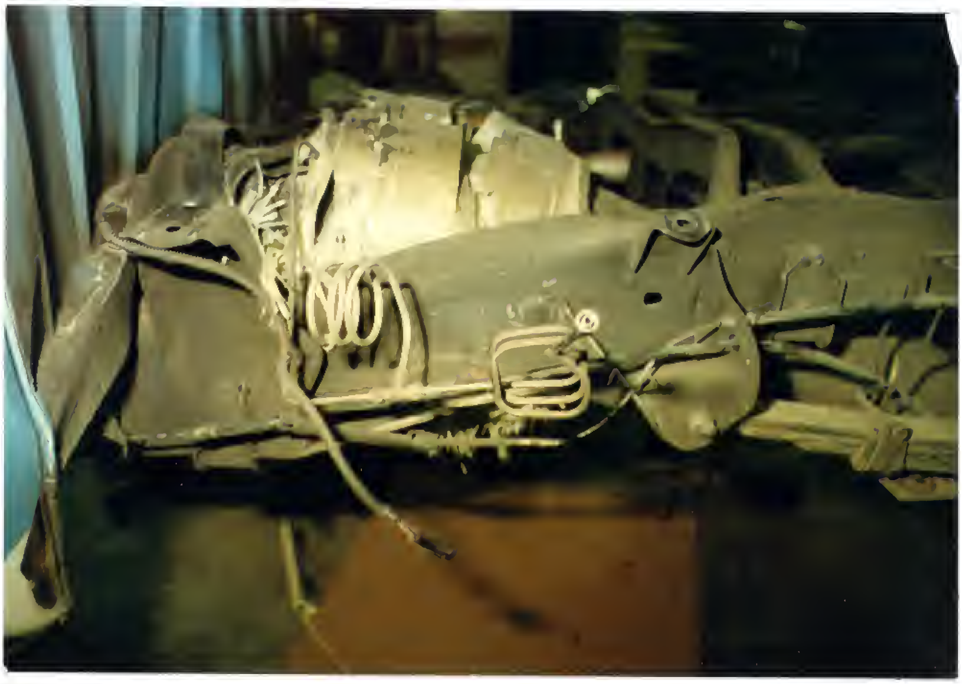

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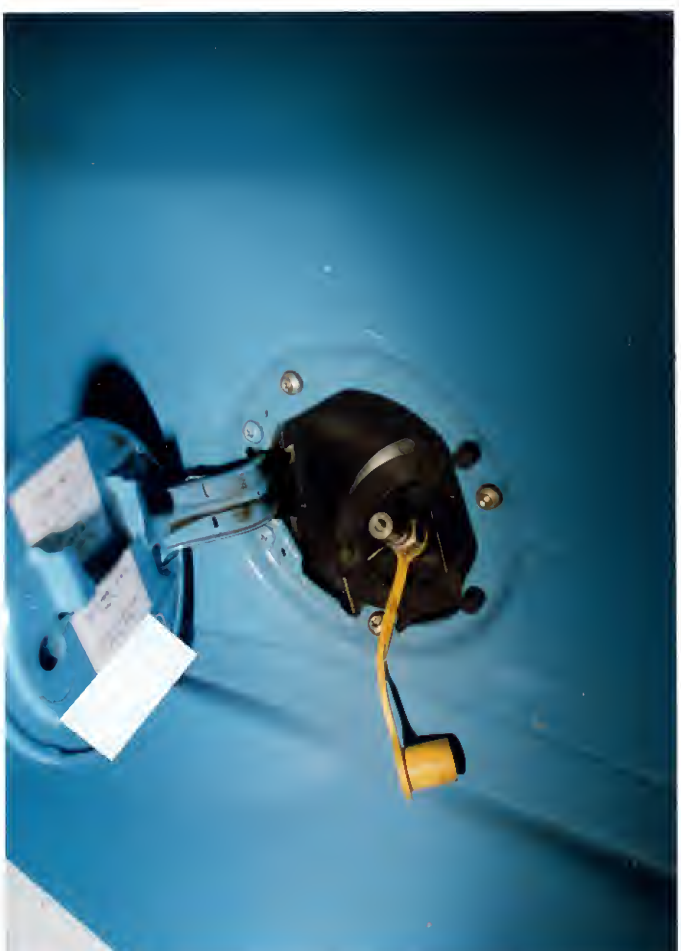

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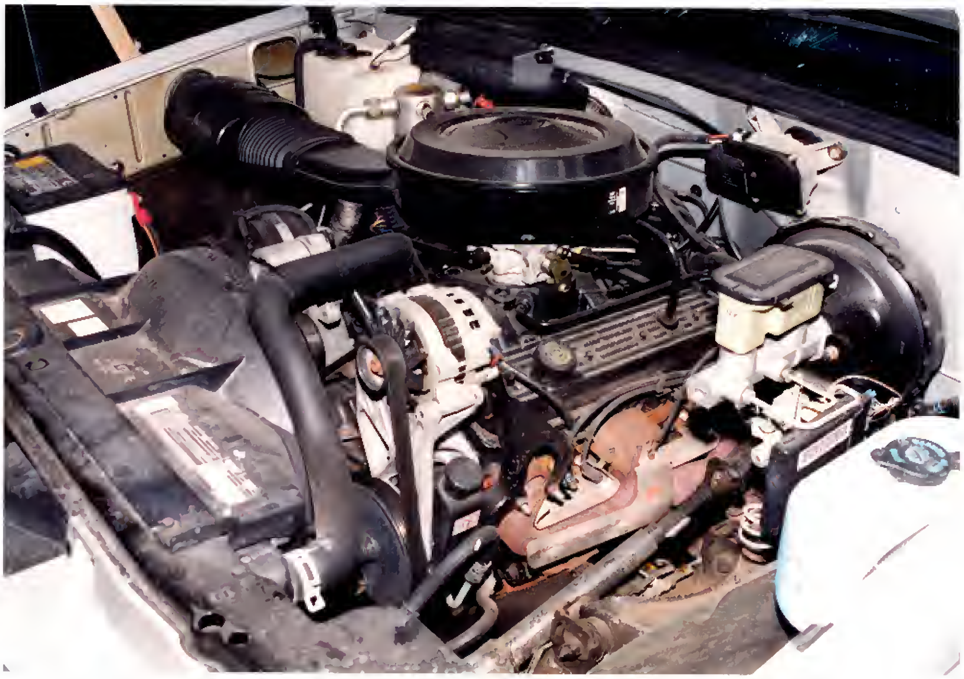

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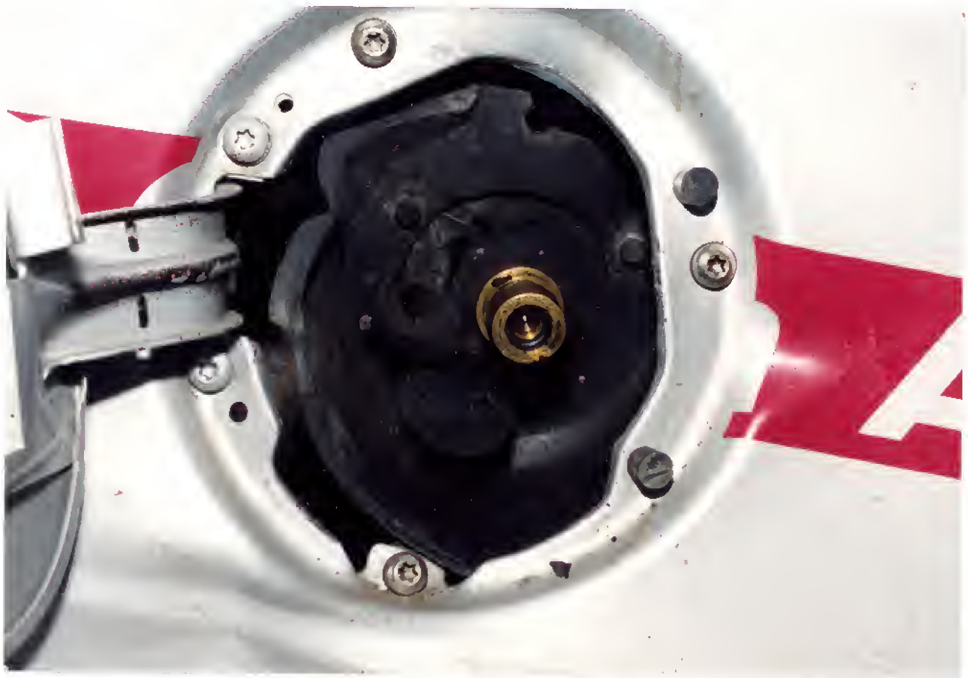

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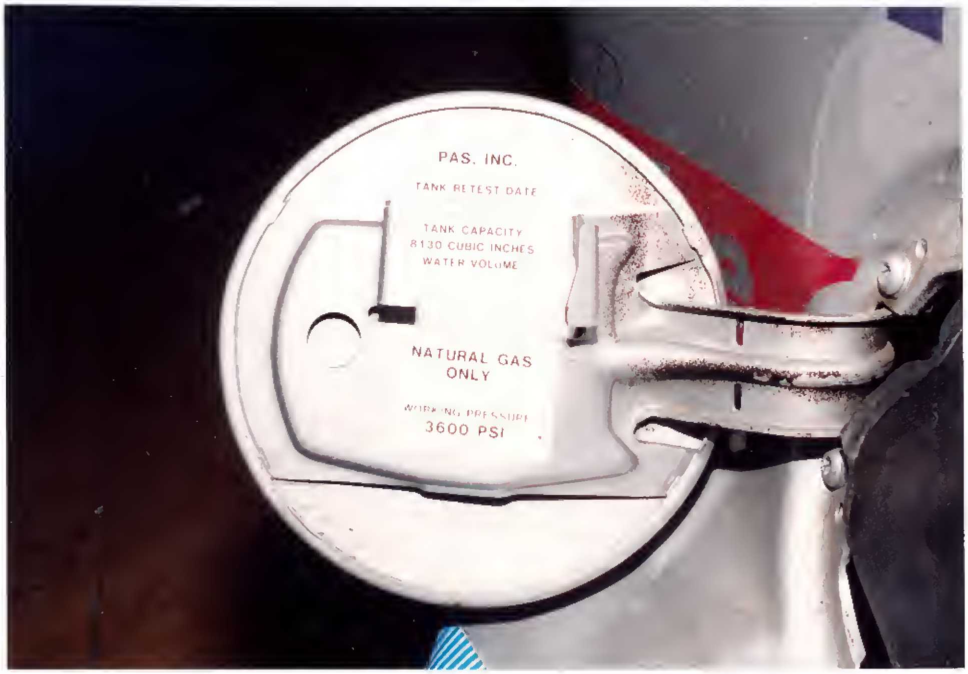

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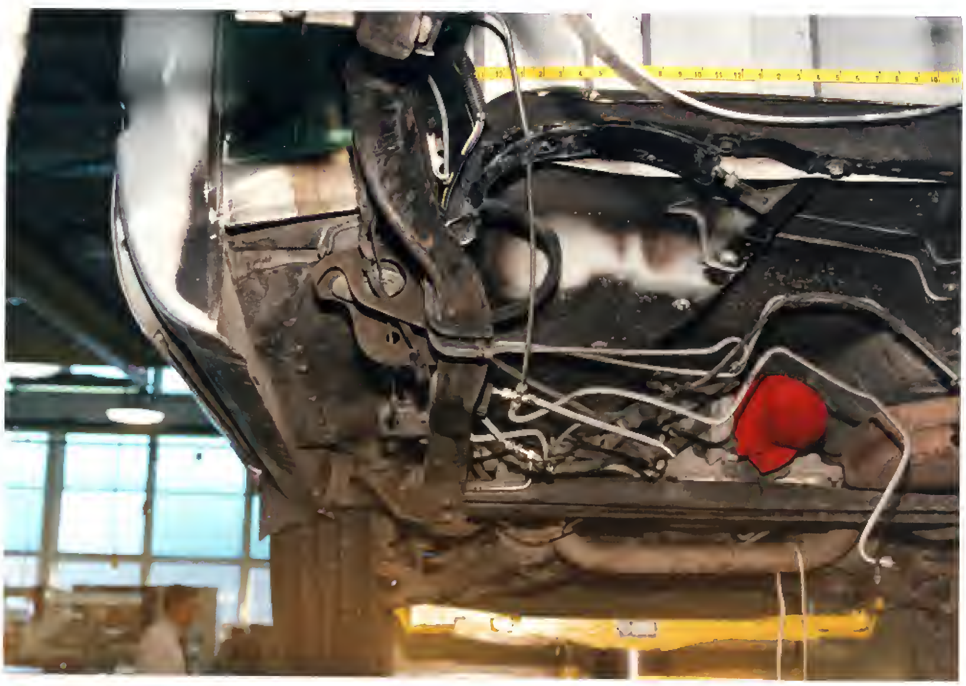

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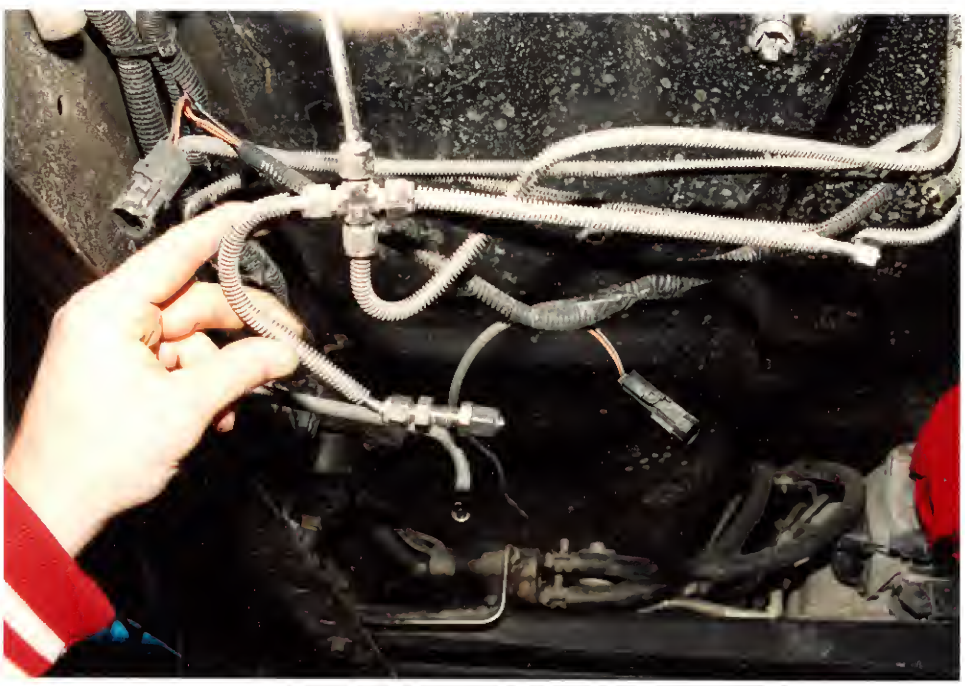

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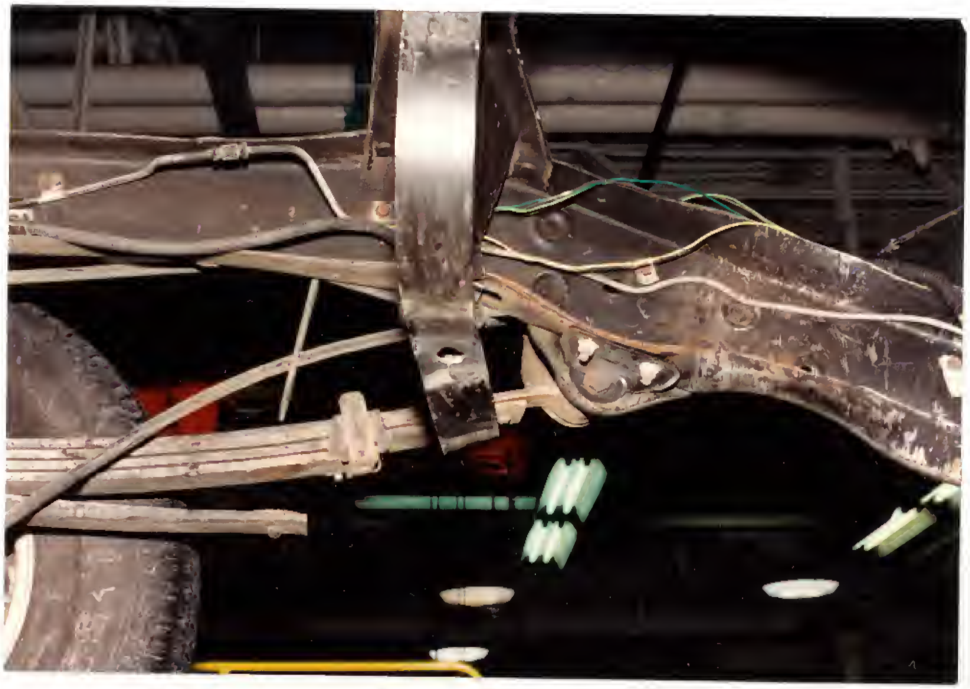

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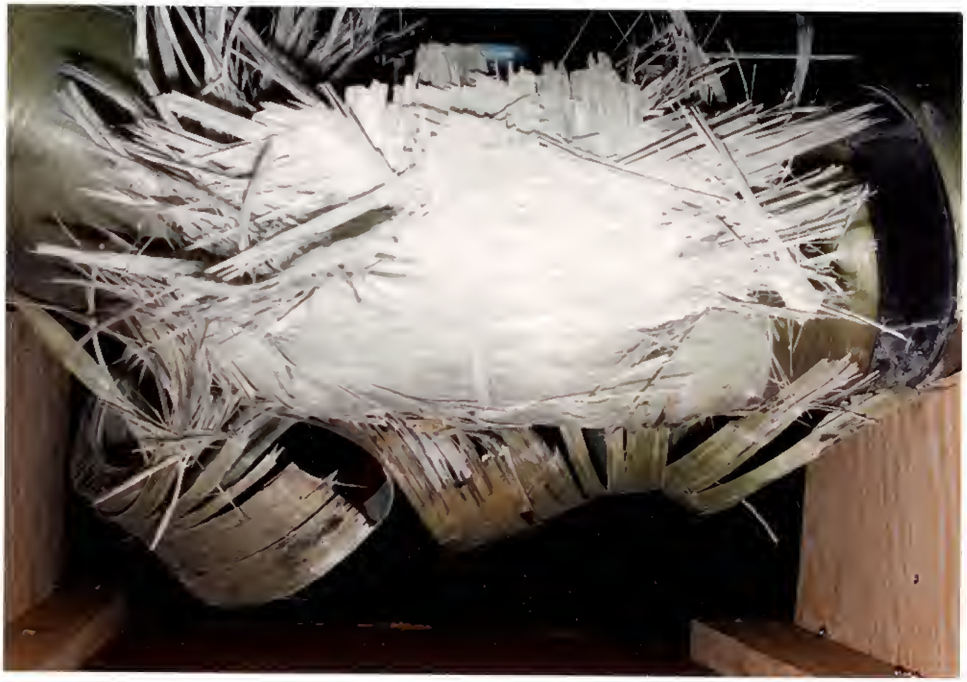

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APPENDIX C

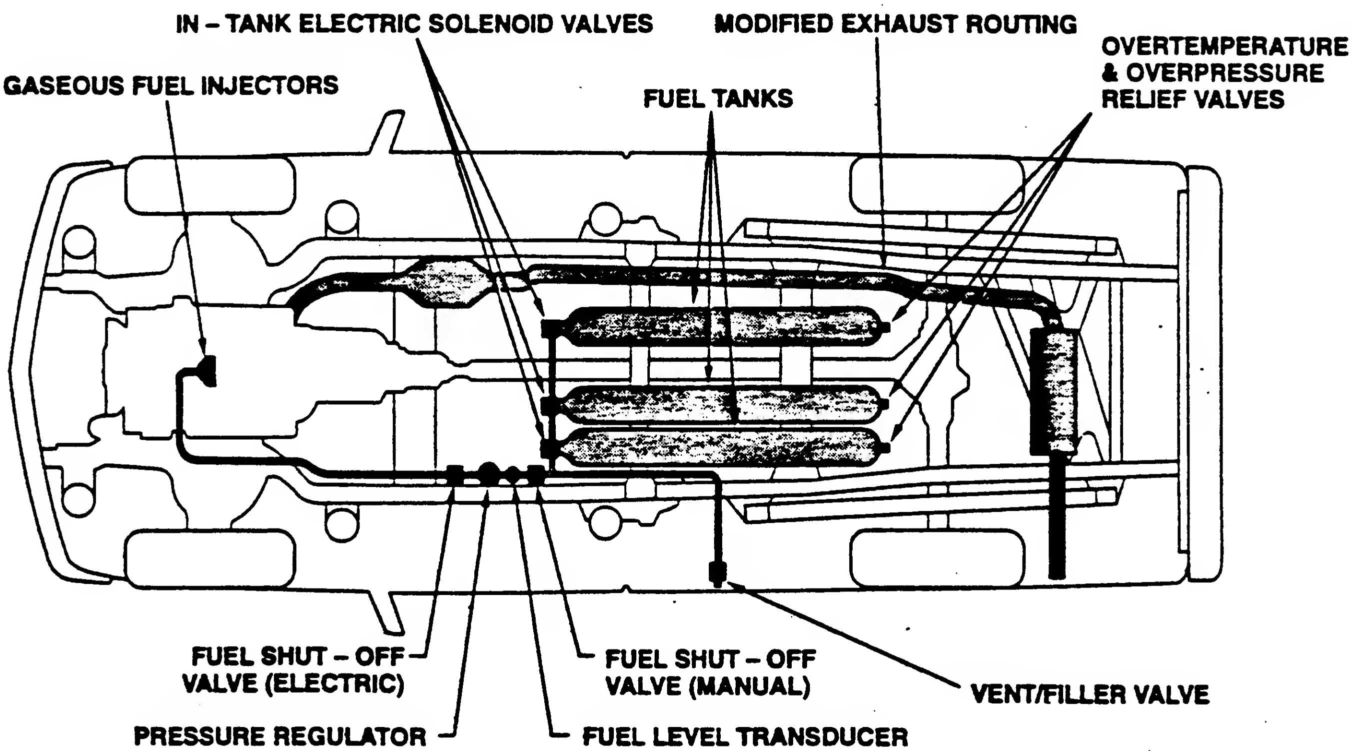
Reference Manual for the PAS CNG Installation

GMC TT-92-00T-2

Reference Manual

NATURAL GAS VEHICLE

Operation and Diagnosis



Natural gas POWERED SIERRA

BEST AVAILABLE

NOTICE !

The Information printed In this manual Is Intended to be used by professional, certified technicians, using the proper tools and equipment. Attempting any of the procedures outlined In this manual without proper authorization, training or supervision, and without the proper tools and safety equipment may cause personal Injury and/or property damage, and therefore Is neither recommended nor Implied.

This reference guide Is not a substitute for the service manual. It Is designed to Introduce you to the natural gas fuel system and outline its basic operation. Some service and diagnosis procedures are Included In this guide to further familiarize you with the system. For complete natural gas vehicle service and diagnosis procedures, refer to the Truck Service Manuals or the 1992 Natural Gas Vehicle Service Manual Supplement.

When servicing the natural gas system or other vehicle systems, use of proper tools is required to ensure safety and correct repairs. Certain tools mentioned in this manual are available through regular GM and Kent-Moore sources. Equivalent tools may be used where noted.

Before servicing any fuel system components, refer to the Service Precautions listed In the Fuel System Service Section of this guide.

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GENERAL DESCRIPTION

VEHICLE OVERVIEW

The engine used in the natural gas powered vehicle is the standard over 8600 GVW 5.7L V-8 engine. This engine is normally equipped with hardened valve inserts and valve rotators, making it readily compatible with natural gas. The major differences between the natural gas vehicle and gasoline powered vehicles are in the components of the fuel delivery system.

Natural gas is a lighter-than-air fuel that comes from the ground. Being lighter than air means that natural gas rises and dissipates rapidly when released into the atmosphere. Some other gaseous fuels, like propane, linger and "pool" at ground level when released.

The compressed natural gas (CNG) fuel system (Figure 1) used on selected 1992 C-Series vehicles is a closed-loop, high pressure system designed only for the use of natural gas. There are no provisions for running on a mixture of gasoline/CNG or to switch back-and-forth between gasoline and CNG. This is a dedicated CNG system.

This vehicle uses a three-way catalyst and exhaust gas recirculation (EGR). There are no evaporative emissions controls since the fuel system is totally closed all of the time. Also, this natural gas vehicle does not need or use an A.I.R. management system.

Natural gas vehicle performance is comparable to gasoline powered versions. However, due to the lower BTU content of natural gas, power output is about 10 percent lower. Some operators of natural gas vehicles may notice the difference, and should simply be made aware that this is not an indication of a problem.

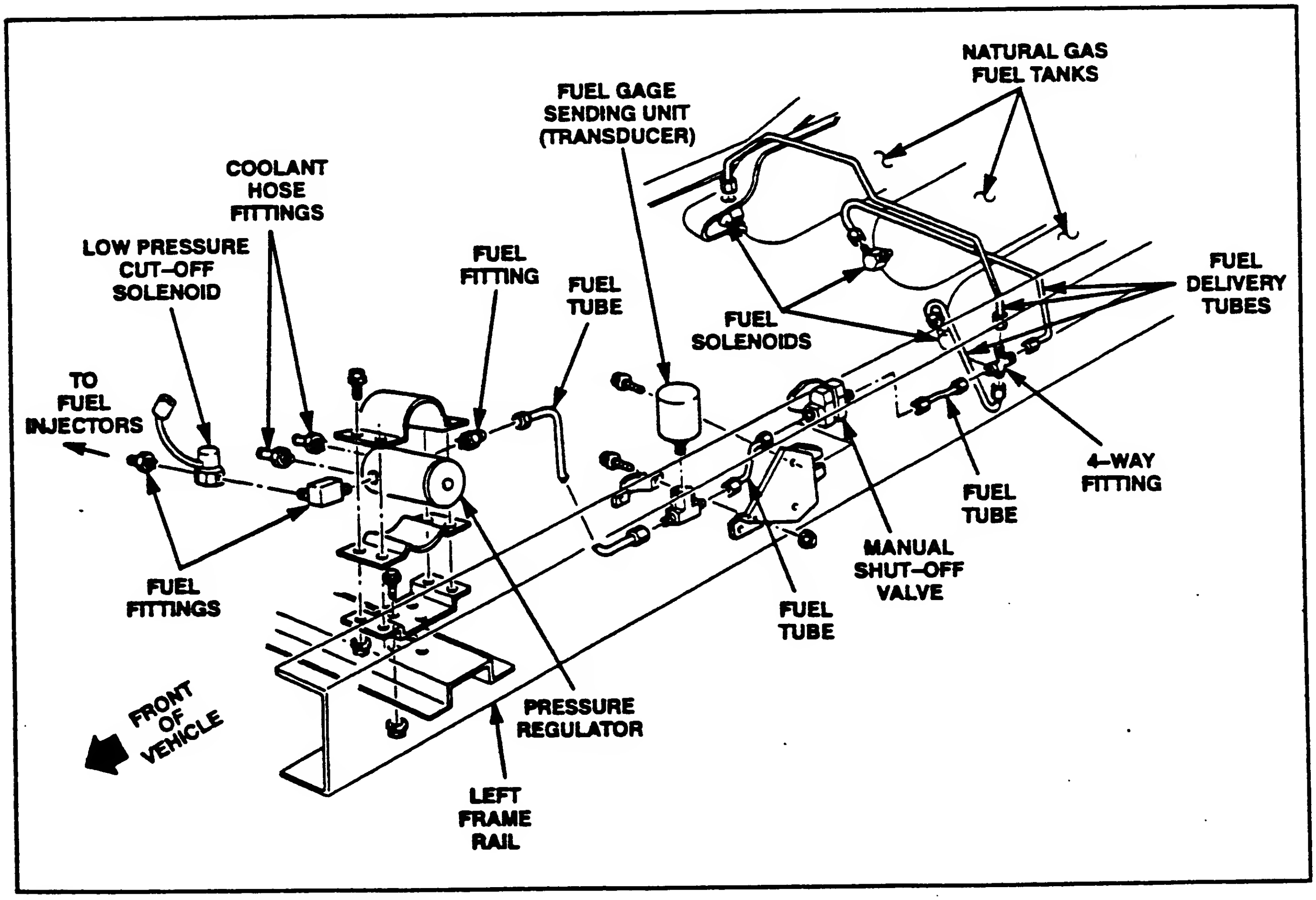


Figure 1 – Natural Gas Fuel System

SYSTEM OPERATION

Since CNG is not a liquid like gasoline, various changes in motor vehicle fuel systems have to be made in order to use it. The most obvious change is the fuel tanks. CNG must be kept under very high pressure in order to carry enough fuel for reasonable intervals between fill-ups. The 3600 psi capacity of the three tanks gives the natural gas powered C-Series vehicle a driving range of about 200 miles. Other changes in the fuel system are explained in the following pages of this manual.

The natural gas fuel system is controlled by a computer processor called the Engine Control Module (ECM). This is the same control module used on gasoline engines, only it uses a PROM chip designed specifically for natural gas engines.

The fuel system consists of three tanks, a pressure regulator, a manual shut-off valve, stainless steel lines and connections, a one-way filler valve, safety relief valves, tank-mounted fuel solenoid valves, a low pressure cut-off solenoid and two fuel injectors. A pressure-sensitive transducer is used in place of the fuel gage sender unit. Refer to Figure 1.

FUEL DELIVERY SYSTEM

WARNING!: CNG FUEL TANKS MAINTAIN UP TO 3600 PSI (24,822 kPa) OF PRESSURE WHEN FULL. ALWAYS FOLLOW THE OUTLINED PROCEDURES IN THE SERVICE MANUAL SUPPLEMENT WHEN SERVICING ANY PART OF THE FUEL SYSTEM. IMPROPER HANDLING MAY RESULT IN PERSONAL INJURY AND/OR PROPERTY DAMAGE.

Fuel Tanks

The fuel tanks are solid-mounted to the vehicle frame forward of the rear axle (Figure 2). When filled, they contain 3600 psi of fuel, which is good for about a 200 mile range. On each tank, there is a two-way fuel solenoid valve and a high pressure, high temperature safety relief valve. The fuel solenoid valves operate together to control fuel flow and tank refilling. Refer to "Fuel Solenoid Valves" for a complete description. The safety relief valves operate independently. Refer to "Fuel Tank Safety Relief Valves" for a complete description.

For removal and installation of the fuel tanks, refer to the Natural Gas Vehicle Service Manual Supplement.

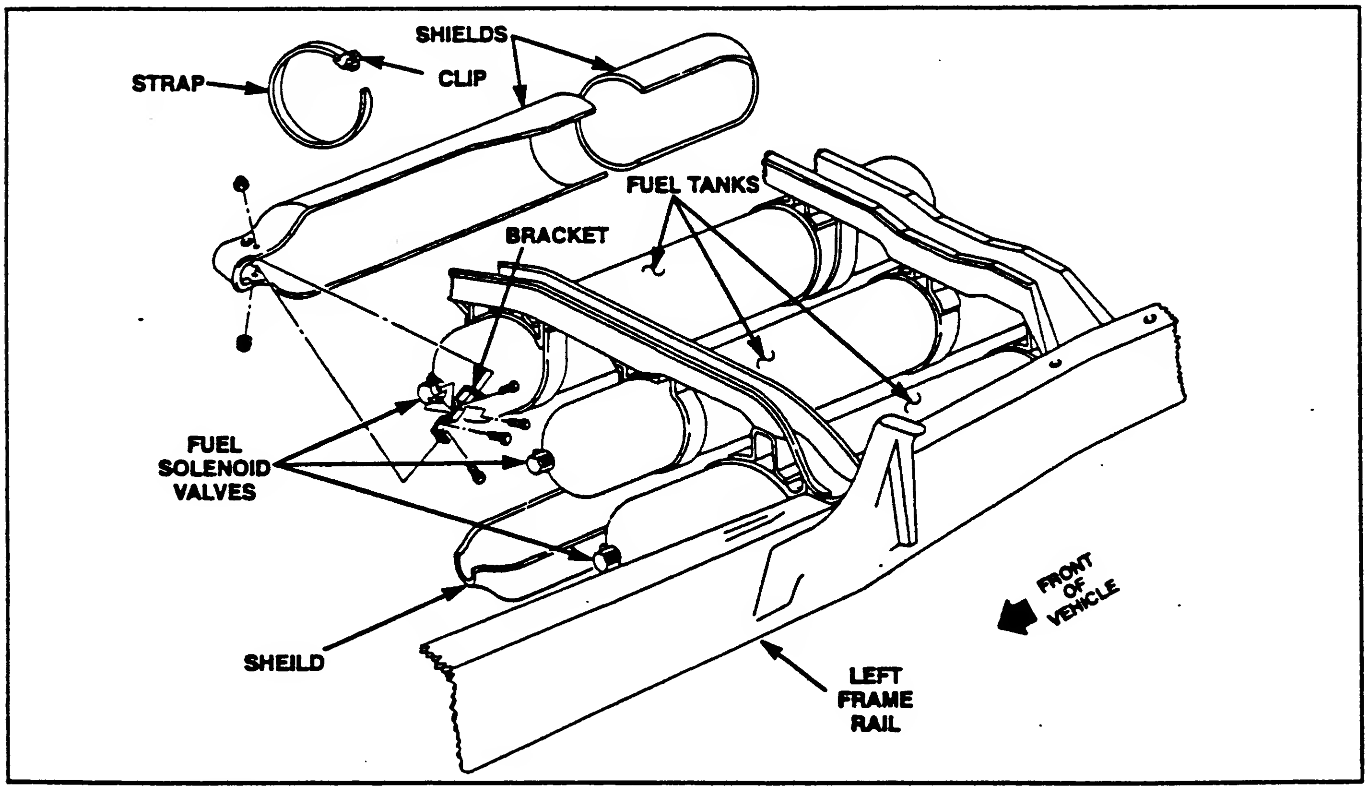


Figure 2 – Fuel Tanks

Fuel Solenoid Valves

A two-way, electric solenoid is mounted on each fuel tank (Figure 3). Each one is tied into the fuel control circuit, just as the electric fuel pump is on a gasoline-powered vehicle. The solenoids open and permit fuel flow when the original fuel pump relay receives an "ignition on" signal, an engine cranking signal or an oil pressure signal. If the ignition switch is only turned to the ON position, the solenoids are activated for only two seconds and then close.

The solenoid valves also control fuel tank filling by keeping the rest of the fuel system closed off when the ignition is off. One-way check valves, forced open by filling pressure, permit fuel to only enter the tanks. Filling is done through separate lines that join at a tee, which is connected by a short line to the filler valve (Figure 4).

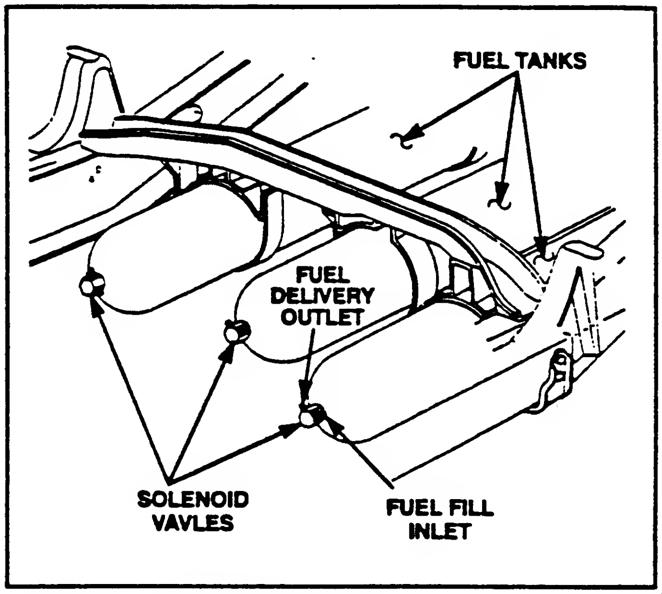


Figure 3 – Fuel Solenoid Valves

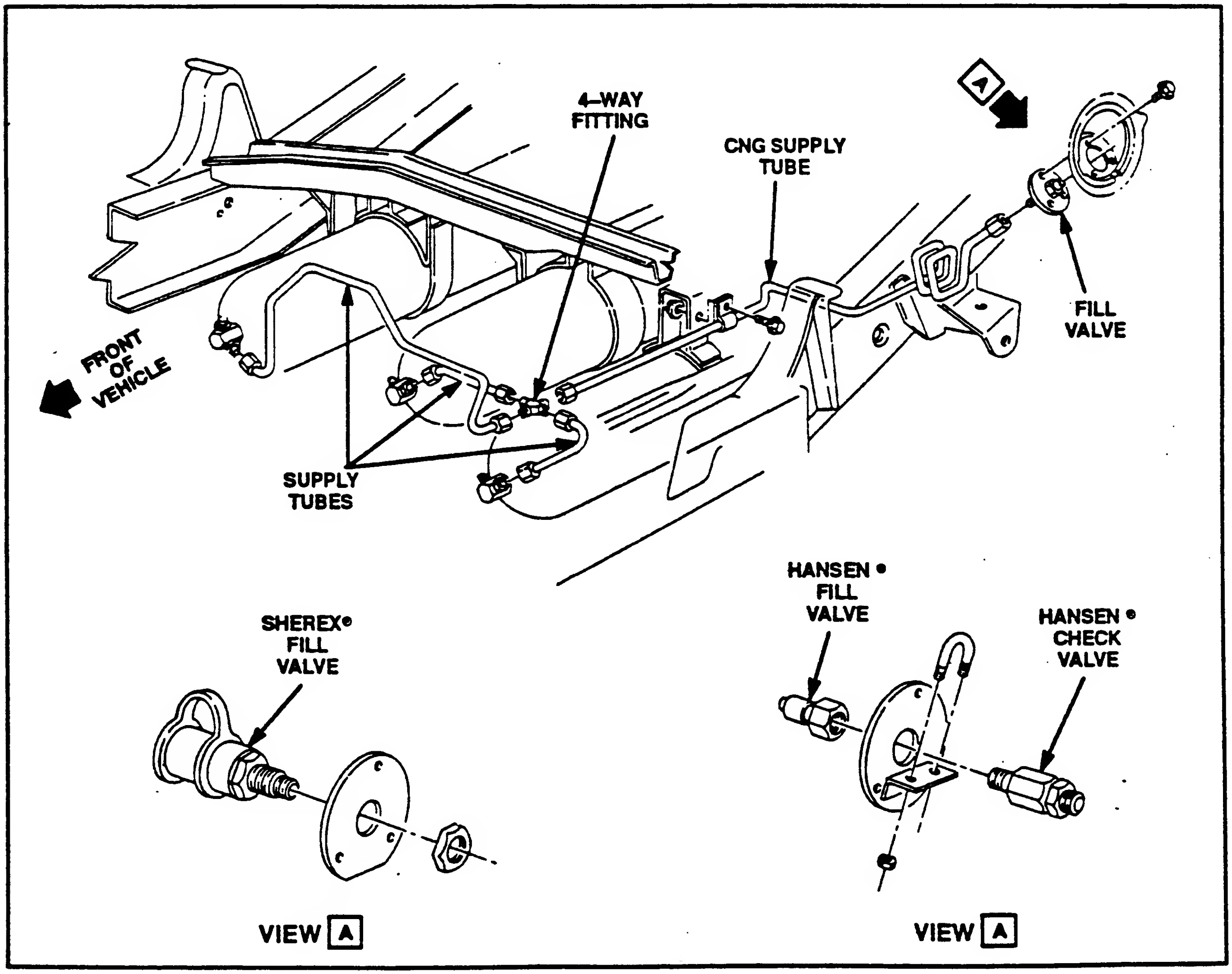


Figure 4 – CNG Filler Valves

Fuel Tank Safety Relief Valves

There is a safety relief valve on the back of each fuel tank. The safety relief valves will rapidly release natural gas pressure whenever they are over-pressurized or heated above 291°F (149°C). It is possible for only one valve to blow while the others remain closed. However, if the vehicle remains running when this occurs, all three tanks will be emptied through the blown valve.

Once a safety relief valve has opened, the fuel tank must be replaced. The valves are not replaceable. Determine the cause of any blown relief valve before replacing the tank and valve assembly.

Filler Valve

The fuel filler valve is located behind the standard fuel filler door. It can be one of two designs, Sherex® or Hansen®, as shown in Figure 4. The one-way filler valve is opened by the pressurized filling equipment, and it also prevents gas from escaping from the tanks if there is a problem with the filling equipment.

Manual Shut-Off Valve

The manual shut-off valve (Figure 5) is located on the chassis left frame rail between the fuel tanks and the pressure regulator. It is a quarter-turn manual valve that shuts off high side fuel pressure. Some state regulations require all natural gas powered vehicles to have exactly this type of valve installed at this location in the system.

The manual valve is open when the knob is horizontal, and the arrow is pointing with the direction of fuel flow. It is closed when the knob is vertical, and the arrow is pointing downward.

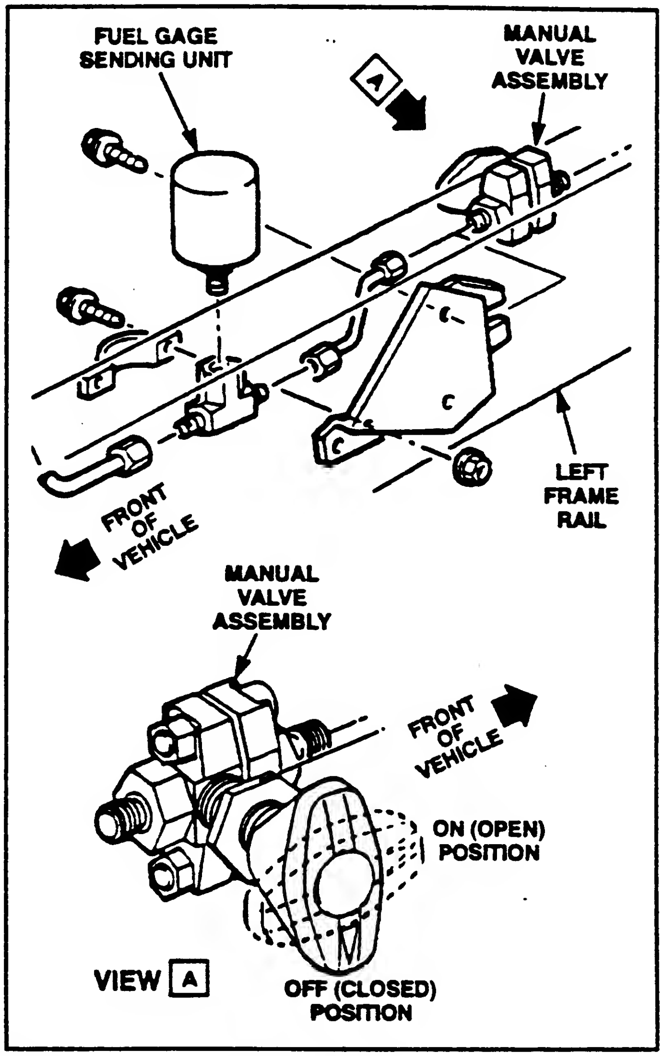


Figure 5 – Manual Shut–Off Valve

Pressure Regulator

The fuel pressure regulator (Figure 6) is located on the left chassis frame rail, downstream from the manual shut-off valve. Fuel enters the regulator at a maximum pressure of about 3600 psi. Fuel leaves the regulator at about 175 psi at idle. Attached to the regulator is the low pressure cut-off solenoid, which closes the low pressure side of the fuel system when the ignition is switched off. Engine coolant is routed through the regulator to keep it from freezing up during cold weather operation.

The fuel pressure regulator is not repairable and must be replaced if it ever leaks or fails to maintain 175 psi (±5 psi). For testing fuel pressure, refer to the Natural Gas Vehicle Service Manual Supplement.

Low Pressure Cut-Off Solenoid

The low pressure cut-off solenoid (Figure 6) is mounted on the pressure regulator. It operates on the same circuit as the fuel valve solenoids. Its main function is to cut off fuel on the low pressure side of the system when the ignition is turned off.

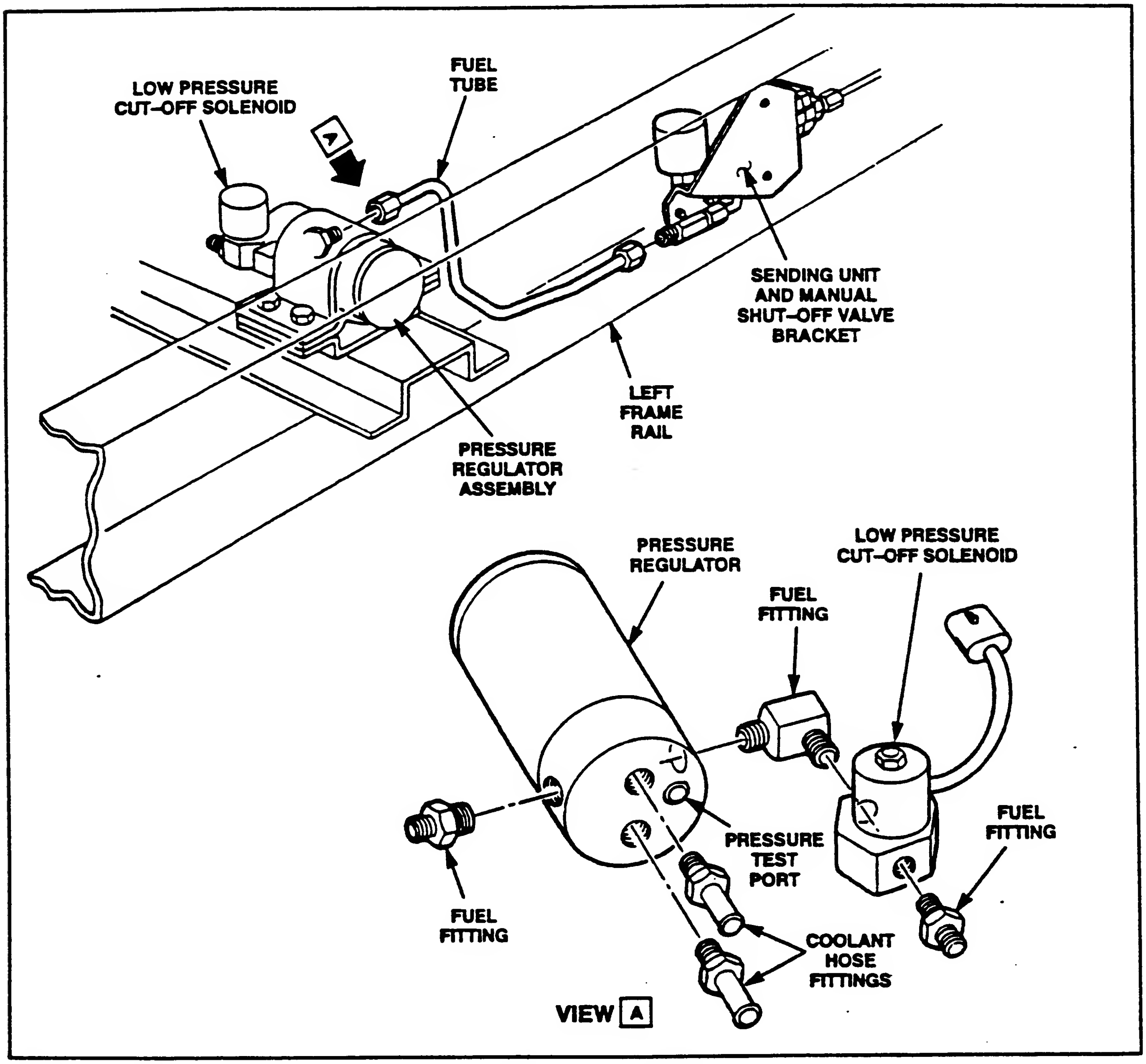


Figure 6 – Fuel Pressure Regulator and Low Pressure Cut-Off Solenoid

Fuel Injectors

The two fuel injectors are mounted in an injector plate, located below the throttle body assembly (Figure 7). These injectors are solenoid-type devices that are operated by the ECM. They are similar in design to gasoline versions, but are made specifically for natural gas use. Injector "on time" is regulated by the same parameters as on a gasoline powered engine.

A spacer plate is used to raise the throttle body slightly on natural gas vehicles. This helps reduce operating noise, since these injectors are not dampened by a liquid fuel.

For complete fuel injector servicing information, refer to the Natural Gas Vehicle Service Manual Supplement.

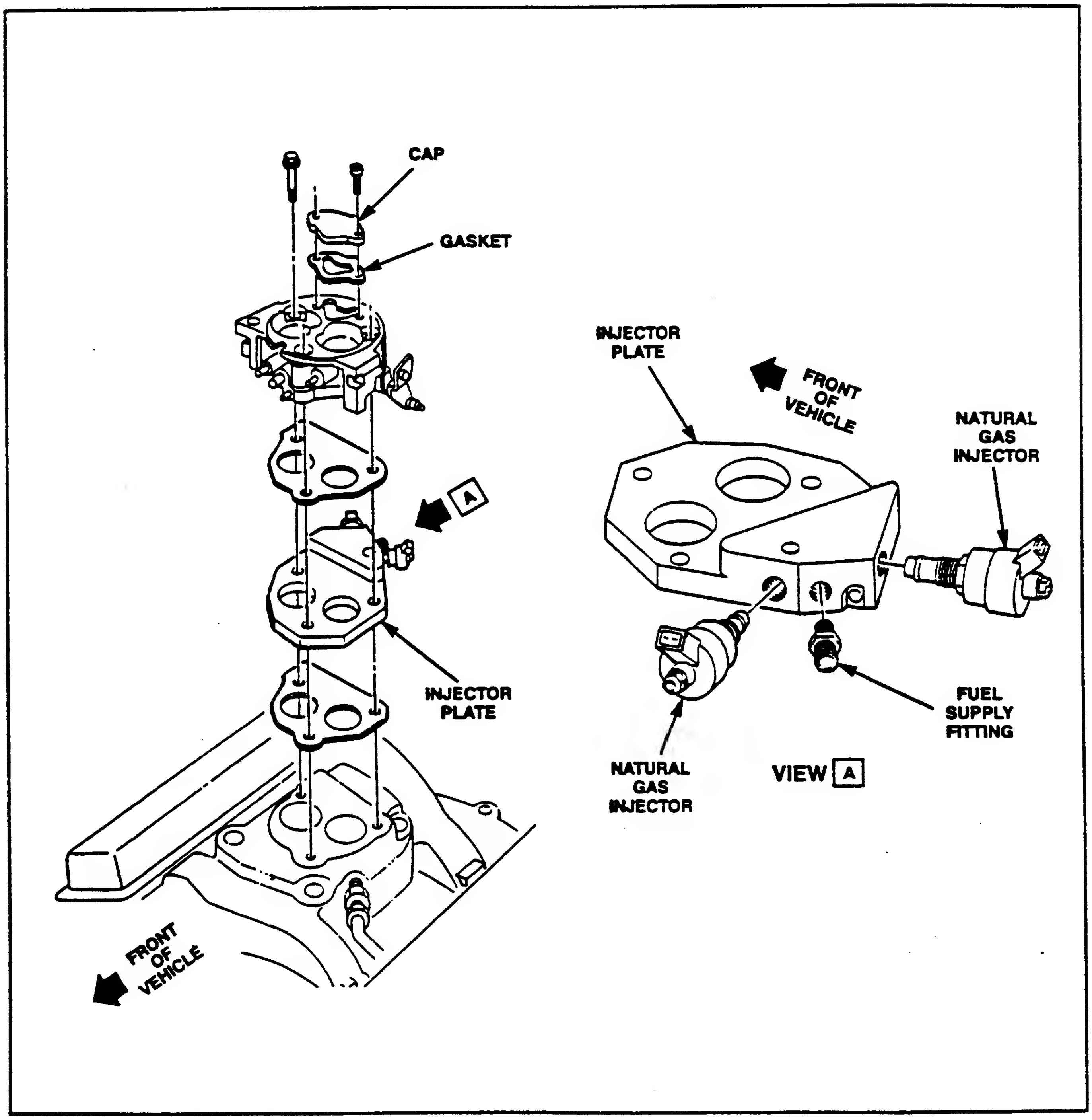


Figure 7 – Throttle Body and Injectors

Fuel Lines

Stainless steel fuel lines are used throughout the vehicle (Figure 8). A short, flexible hose is used between the regulator and the engine-mounted line to compensate for normal driveline movements and vibrations. All line-to-line and line-to-fitting connections are compression-type fittings, and require no sealers or O-rings. Some fuel fittings installed to components do have pipe threads, and require anaerobic pipe sealer with Teflon® for proper installation.

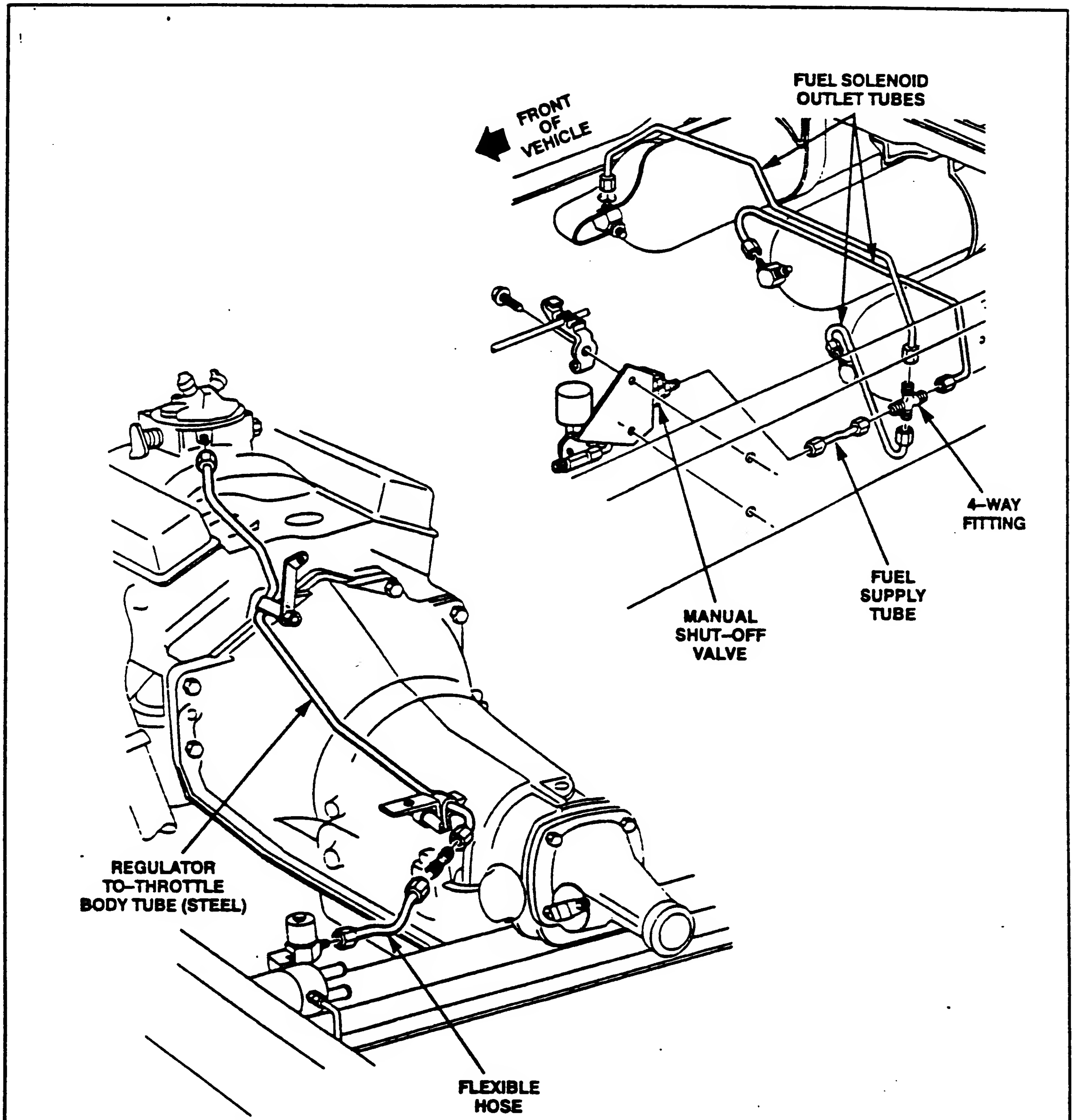


Figure 8 – Fuel Lines and Typical Connections

FUEL CONTROL ELECTRICAL SYSTEM

Overview

Fuel delivery control on the natural gas vehicle (Figure 9) is very similar to gasoline powered vehicles. The fuel control relay still relies on signals from ignition, engine cranking and oil pressure. Instead of a fuel pump though, the fuel pump signal is used to turn on the fuel solenoids mounted on the fuel tanks. Parameters that control whether the solenoids are open or closed are also the same as those for a gasoline powered vehicle. An additional solenoid is installed on the pressure regulator to shut off the low pressure side of the system. For complete fuel control system service, refer to the Natural Gas Vehicle Service Manual supplement.

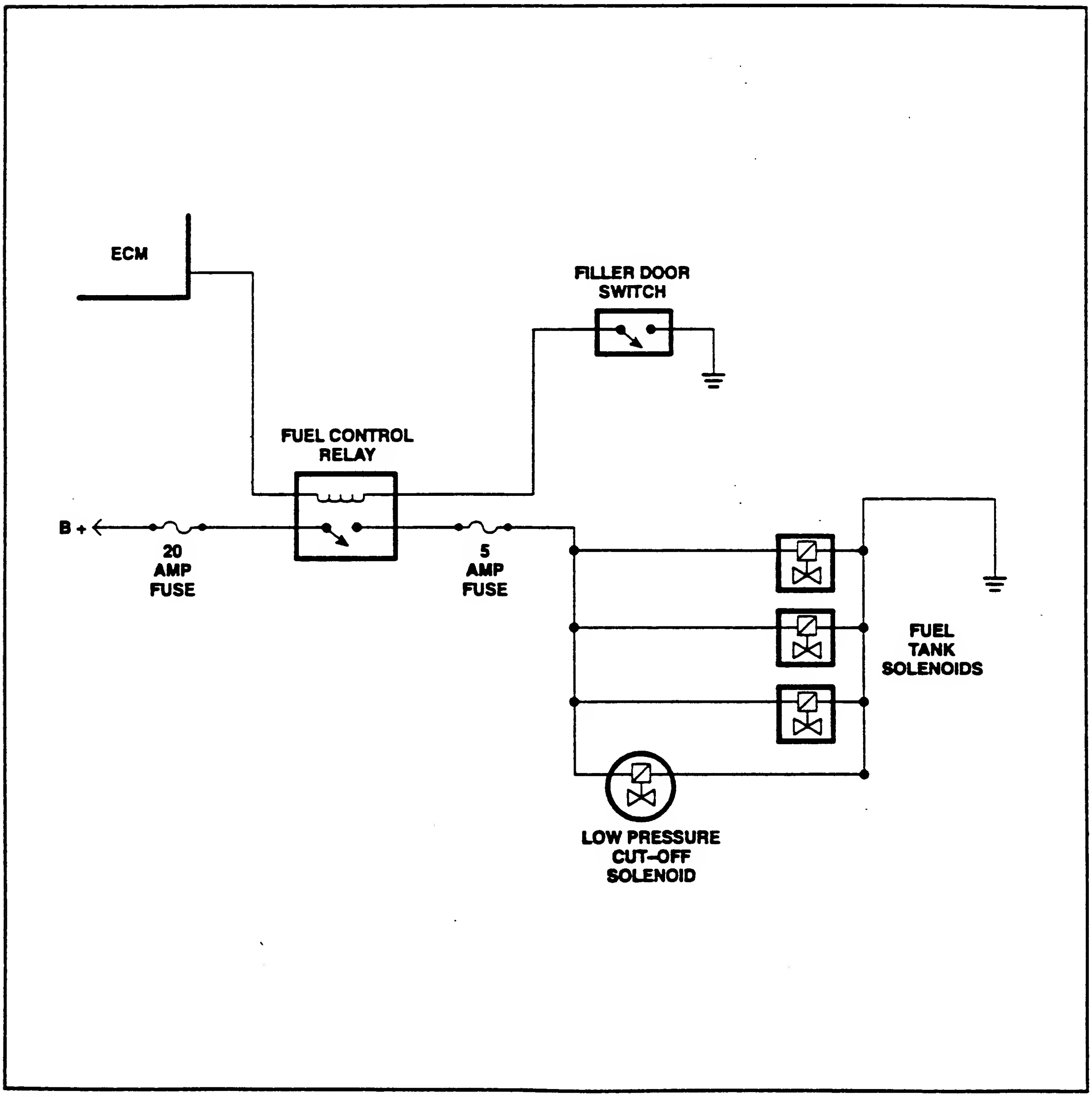


Figure 9 – Natural Gas Fuel Control Circuit Diagram

Fuel Filler Door Switch

A fuel filler door switch, much like the driver and passenger door switches, is installed in the natural gas vehicle filler door area (Figure 10). This switch is part of the fuel delivery circuit. It prevents the engine from being started during fill-ups or anytime the filler door is open, thus eliminating the possibility of the vehicle being driven off with a high pressure filling hose still attached.

The switch is mounted inside the body panel near the filler door, and is connected in series with the ground circuit for the solenoid valve relay (Figure 9). When the filler door is opened, the solenoid valves can no longer be grounded, and will not allow fuel to pass into the delivery lines.

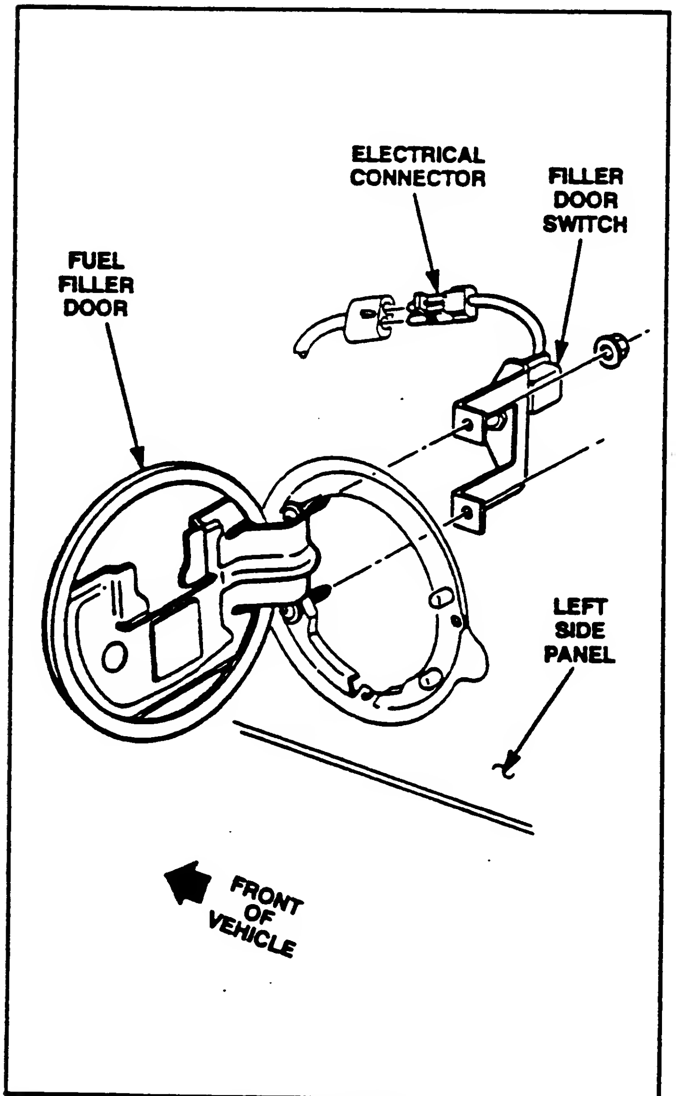


Figure 10 – Fuel Filler Door Switch

FUEL INDICATING SYSTEM

Fuel Gage

The standard fuel gage and wiring circuit are used in the natural gas vehicle.

Sending Unit (Pressure Transducer)

A pressure-sensitive transducer (Figure 11) replaces the standard float-type sending unit. The transducer is a sensor which provides a compatible electrical signal to operate the fuel gage. As fuel is used, pressure in the high side of the system drops, causing a reduced resistance to ground at the transducer. The fuel gage then displays the lower pressure as remaining fuel.

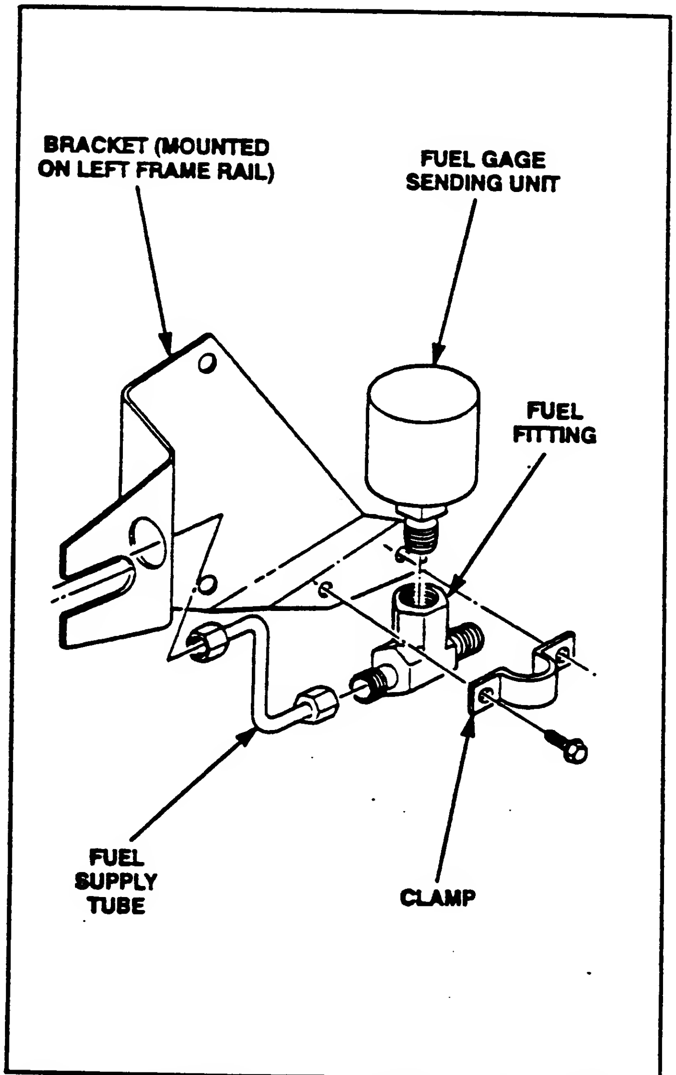


Figure 11 – Fuel Gage Sending Unit (Transducer)

The fuel gage electrical circuit (Figure 12) remains the same, with the transducer substituting for a float.

EXHAUST AND EMISSIONS SYSTEMS

Exhaust System

The placement of the CNG fuel tanks has resulted in a re-routing of the exhaust system components beyond the catalytic converter (Figure 13).

Because of this new routing, the spare tire mount under the cargo bed has been removed. If a spare tire is desired, RPO P13, for a cargo bed-mounted spare, must be included with the Natural Gas package for this vehicle.

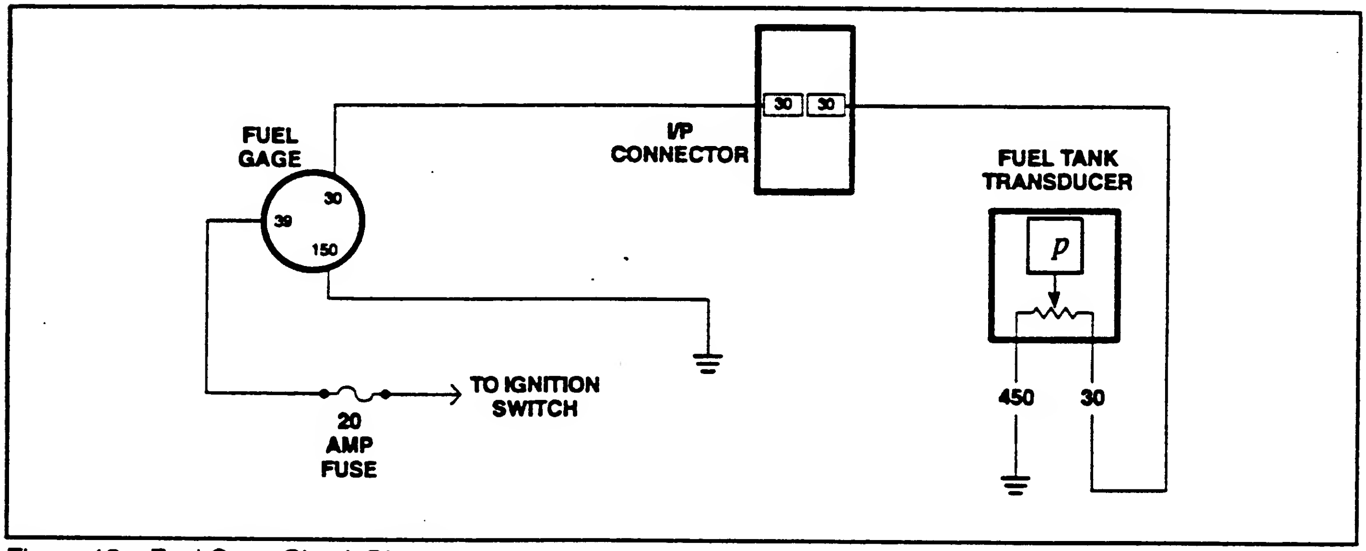


Figure 12 – Fuel Gage Circuit Diagram

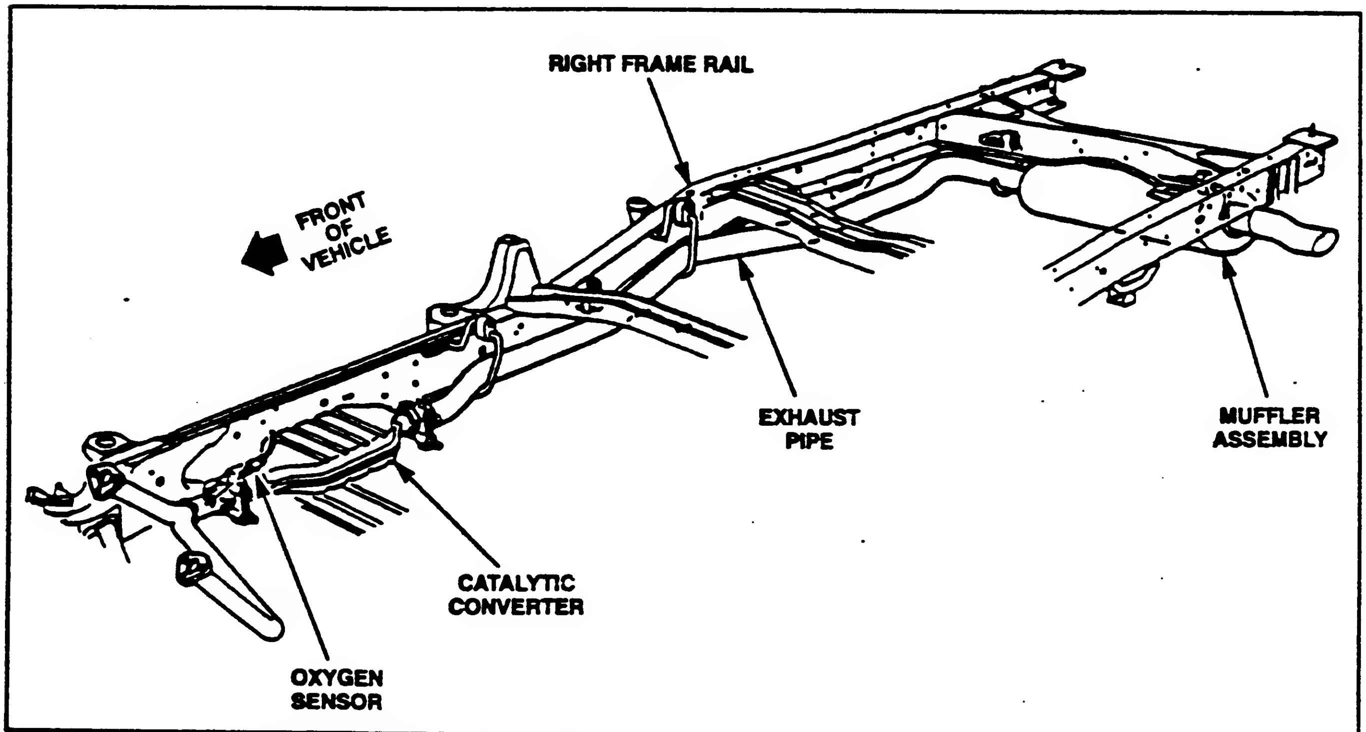


Figure 13 – Natural Gas Vehicle Exhaust Routing

Exhaust Emissions

Exhaust emission controls on natural gas vehicles consist of a catalytic converter and exhaust gas recirculation. The systems are the same as those on gasoline powered vehicles. For complete service information, refer to the regular Truck Service Manuals.

Evaporative Emissions

Even though natural gas is a hydrocarbon fuel, an evaporative emission control system is not needed because this vehicle must use a completely closed fuel system.

A.I.R. System

An A.I.R. system is not required on natural gas powered vehicles.

Positive Crankcase Ventilation (PCV)

The PCV system on the natural gas vehicle is the same as on gasoline powered vehicles.

Thermostatic Air Cleaner (THERMAC)

The thermostatically controlled air cleaner intake system is the same as on gasoline powered vehicles.

ELECTRONIC ENGINE CONTROLS

Most engine management controls on natural gas vehicles are the same as those for gasoline powered vehicles. There is a special PROM chip for the ECM, but existing 1992 diagnostics are otherwise the same.

Heated Oxygen Sensor

A heated oxygen sensor is used on natural gas vehicles, but testing procedures remain unchanged. Heated oxygen sensor voltages fall within the already established specifications.

Ignition System and Knock Sensor

The ignition system used on natural gas vehicles is the same as used on 5.7L gasoline engines. Due to the high octane rating of natural gas, the knock sensor would actually reduce engine performance. Therefore, the knock sensor signal to the ECM is electronically hidden, and no knock sensor data will be received by the TECH 1 tester during diagnosis.

DIAGNOSIS AND TESTING

NOTE: ***Complete NGV diagnostic procedures are not provided in this guide. Always refer to the complete diagnosis procedures printed in the Natural Gas Vehicle Service Manual Supplement.***

FUEL SYSTEM

NOTE: ***Whenever a fuel system component has been serviced, pressurize the system and check for fuel leaks using a soapy water solution.***

Relieving Fuel Pressure

Before servicing any part of the fuel system forward of the manual valve, relieve fuel system pressure as follows:

1. Close the manual valve.
2. Start the engine and allow it to stall.
3. Turn the ignition off.
4. Do not open the manual valve until repairs are completed.

To relieve fuel system pressure between the solenoid valves and the manual valve, partially loosen a fuel line connection and allow the fuel pressure to slowly bleed off.

WARNING!: THE IGNITION SWITCH MUST BE OFF WHILE RELIEVING FUEL PRESSURE.

WARNING!: CNG FUEL TANKS MAINTAIN UP TO 3600 PSI (24,822 kPa) OF PRESSURE WHEN FULL. ALWAYS FOLLOW THE OUTLINED PROCEDURES IN THE SERVICE MANUAL SUPPLEMENT WHEN SERVICING ANY PART OF THE FUEL SYSTEM. IMPROPER HANDLING MAY RESULT IN PERSONAL INJURY AND/OR PROPERTY DAMAGE.

Fuel Pressure Test

NOTE: ***The fuel pressure regulator cannot be repaired for leaks or pressure readings out of specifications. It must always be replaced.***

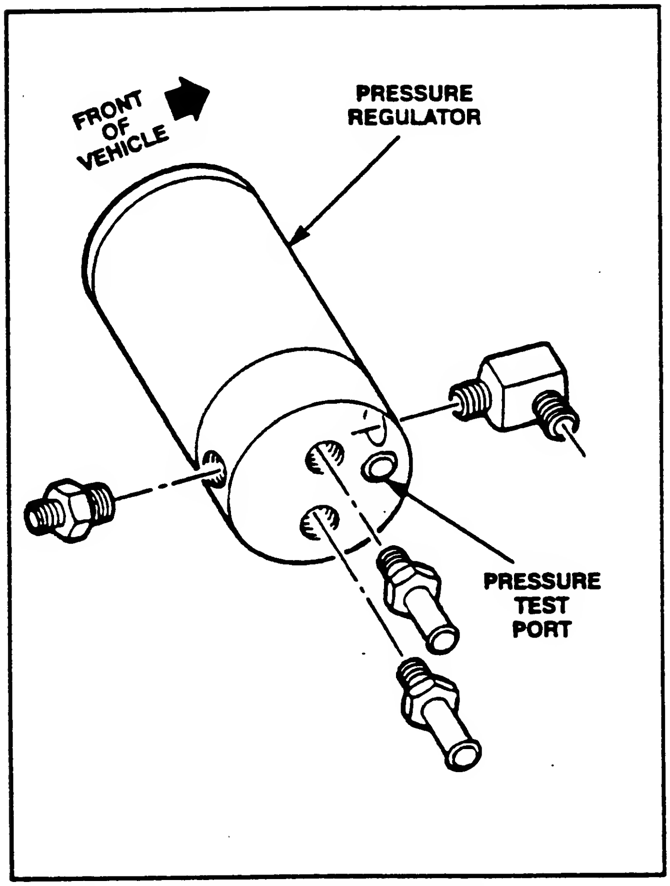


Figure 14 – Pressure Test Port Location

To check fuel pressure, you will need the Kent-Moore Pressure Gage, number J-21867, or an equivalent high pressure gage capable of safely reading 200 psi (1,380 kPa).

1. Install the pressure gage to the test port on the fuel pressure regulator (Figure 14).

2. Start the engine and allow it to idle.

NOTE: ***Engine must run at an idle during fuel pressure tests.***

3. Check the gauge reading. It should read 175 psi, +/-5 (1,207 kPa, +/-34.5).

4. If the regulator maintains less than 170 psi (1,172 kPa), check for leaks using your sense of smell and the soap-and-water method. The usual lean symptoms will be present, and integrator/block learn values above 128 will be found when you perform electronic testing.

If the regulator maintains more than 180 psi, the usual rich symptoms will be present and integrator/block learn values below 128 will be found when you perform electronic testing.

5. Repair any leaks found. Refer to Fuel System Leak Test. Be sure to use a semi-liquid anaerobic pipe sealant containing Teflon, or T-F-E, when installing any threaded components you removed. Repeat the pressure test.

6. If no leaks are found, or if fuel pressure was above 180 psi (1,241 kPa), replace the regulator and repeat the pressure test. Be sure to use a semi-liquid anaerobic pipe sealant with Teflon or T-F-E, when installing fuel fittings to the new pressure regulator.

Fuel System Leak Tests

Minor leaks in the fuel system are difficult to locate. If a leak is suspected, apply a soap and water solution to all fittings and component connections. If a leak is present, the soapy water will bubble.

NOTE: Leak testing should always be performed after any component is replaced.

Fuel Tank Solenoid Test

A limited fuel range concern may be due to one or two of the fuel tank solenoids not operating. For example, if the vehicle can only be driven for about a third of its normal expected range before needing to be refueled, only one fuel tank (a third of capacity), may have a functional solenoid valve.

To test the solenoids individually, use the following procedure:

1. Position the vehicle on a hoist.
2. Raise the vehicle and disconnect all three fuel tank solenoid valves.
3. Lower the vehicle and start the engine, allowing it to use up the remaining fuel in the lines and stall.
4. Raise the vehicle and connect one solenoid. Lower the vehicle.
5. Turn the ignition switch to the "on" position, and watch the fuel gage. If the gage indicates fuel is present, the solenoid that is presently connected is working.
6. Repeat the procedure, emptying out the system each time, for each solenoid. If a solenoid valve is not operating and is receiving power and ground, the fuel gage will indicate no fuel. Replace the solenoid(s) as described in the Natural Gas Vehicle Service Manual Supplement.

ELECTRICAL SYSTEM

Fuel Gage Circuit Tests

The natural gas fuel gage circuit is diagnosed just like a gasoline vehicle's fuel gage circuit, only the sending unit is a pressure-sensitive transducer instead of a float-type variable resistor.

- If the gage reads beyond full at all times, check for an open in the sender wire.
- If the gage reads empty at all times, check for a short-to-ground in the circuit.
- If the wiring is okay, you must determine if the gage or the sending unit (transducer) is malfunctioning. To do this, disconnect the wiring connector at the sending unit. The fuel gage should now read over the full mark (with the ignition on). Connect a jumper wire and ground the sender wire to the chassis. The gage should now read empty. If the gage does not operate this way, replace the gage. If the gage operates properly, replace the transducer.

Fuel System Electrical Testing

The fuel system circuit is very similar to those for comparable gasoline powered vehicles, and electrical testing is also similar. The following unique conditions apply to natural gas powered vehicles:

- A "no start" condition may be due to a blown in-line fuse. The fuse is located on the "hot" side of the circuit, in the wiring harness near the transducer.
- A "no start" condition may also be due to an open fuel filler door or an open in the filler door switch or its wiring. Remember that the filler door switch is in the ground side of the fuel control circuit.
- The "ignition on," crank and oil pressure signals are sent to three fuel control solenoids on the natural gas vehicle, as opposed to the fuel pump on a gasoline vehicle. The existing fuel pump relay is still used. If the wiring and relay are okay, the problem may be in one of the fuel control solenoids.

Electronic Controls Testing

Testing the system electronic controls can be performed using the Tech I Tester and following the diagnostic procedures in the 1992 Light Duty Truck Fuel and Emissions Service Manual or the Natural Gas Vehicle Service Manual Supplement. You can use the 1992 PCM cartridge in the Tech I. The only difference is that you should ignore any knock sensor information.

Emissions Testing

Emissions tests on the natural gas vehicle are the same as those for comparable gasoline powered vehicles. Refer to the 1992 Light Duty Truck Fuel and Emissions Service Manual for test procedures.

FUEL SYSTEM SERVICE

NOTE: ***Complete NGV service procedures are not provided in this guide. Always refer to the complete service procedures printed in the Natural Gas Vehicle Service Manual Supplement.***

COMPONENT REPLACEMENT

Complete removal and installation procedures for natural gas fuel system components are included in the Natural Gas Vehicle Service Manual Supplement. System Components that are individually replaceable include:

- fuel tanks
- fuel solenoid valves
- filler valve
- manual shut-off valve
- regulator
- low pressure cut-off solenoid
- fuel injector plate
- fuel injectors
- fuel gage sending unit
- fuel lines and fittings

None of the above components are serviceable. If a component is malfunctioning, it must only be replaced as a unit.

SERVICE PRECAUTIONS

The following are general precautions to be observed when servicing natural gas fuel system components:

- DO NOT SMOKE **when servicing any part of the fuel system.**
- **Natural gas is toxic when concentrated in a small area. Always work in a well-ventilated area when releasing natural gas fuel into the air. If possible, release as much fuel pressure as you can outside of the shop.**
- DO NOT VENT THE FUEL SYSTEM OR PERMIT HIGH VOLUME LEAKS IN SHOPS WITH OVERHEAD OPEN FLAME-TYPE HEATERS. **Remember, natural gas rises quickly!**
- Always work away from open flames or sparks. Do not weld or carry an open flame near the fuel system if you smell gas or otherwise suspect a leak.
- Compressed natural gas fuel systems are under extremely high pressure at all times. Whenever working on a high-pressure component, always relieve pressure by slightly loosening the component.
- When working on a low-pressure component, always shut off fuel pressure at the manual shut-off valve first.
- When replacing threaded components, always apply an anaerobic pipe sealant containing Teflon or T-F-E, to the new component threads.
- Always test for leaks with soapy water after any service is performed.
- As with any vehicle, always connect an exhaust hose to the tail pipe whenever the engine is running in the shop.

SPECIFICATIONS

VEHICLE:

Application	3/4-ton, full-size pickup
Gross Vehicle Weight (GVW)	7200 lbs. (3266 kg)
Axle Ratio	3.42

ENGINE:

Application	5.7L EFI V8
Modifications	revised throttle body & injectors

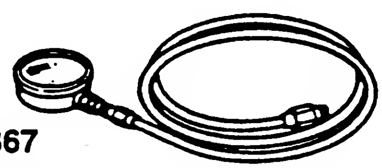
FUEL SYSTEM:

Type	closed-loop natural gas

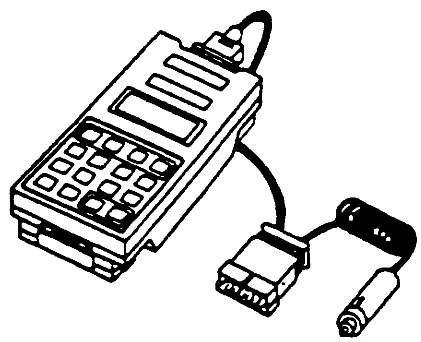
FUEL TANKS:

Type	certified CNG storage-type
Quantity	3
Approximate Weight (Empty)	70 lbs (31.8 kg)
Approximate Weight (Full)	90 lbs (40.8 kg)
Pressure Capacity	3600 psi (24,822 kPa)
Cruising Range (Est., Tanks Full)	200 miles (322 km)
Gas Volume (Each, Full)	462.5 cu. ft. (13,101 litres)

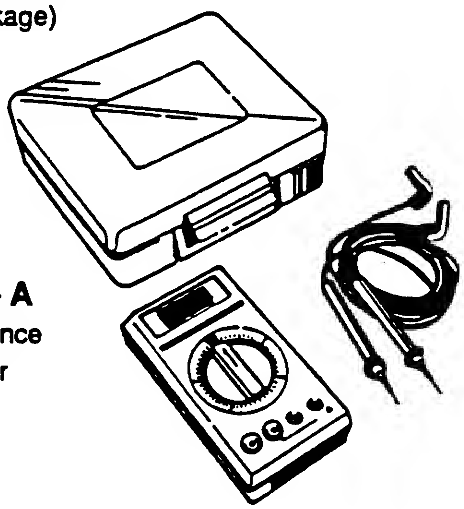
SPECIAL TOOLS



J 21867
Universal Pressure
Gage Set (0 – 300 psi)
(from prior essential
tool package)



94–00101–A
TECH 1 Tester



J 34029 – A
High Impedance
Multimeter

SPECIAL NOTICE TO DEALERS

Labeling of Natural Gas Vehicles is governed by state, county and municipal regulations. Typical locations for labels on natural gas vehicles include:

- Lower right portion of tailgate, indicating the presence of compressed natural gas.
- Lower rear portion of driver's door, indicating the location of the manual shut-off valve.

Be sure to check with local authorities to see if any unique vehicle labels are required. Your dealership is responsible for complying with ALL such local regulations before delivering the vehicle to the customer.

Some states, counties and/or municipalities may also require any technician who works on natural gas vehicle fuel systems to be certified in CNG systems. Check with your local automotive regulations bureau for the requirements in your area.

POST-TEST

The following post-test should be used as an additional learning tool, as well as to test what you have learned in this program. Complete the test only after you have viewed the video and read the reference material. If there are some questions you cannot easily answer, stop and reread the necessary portions of the reference material, or review the video tape.

INSTRUCTIONS

USE A PENCIL, No.2 or darker, when filling out all the information and test answers on the answer sheet. Using a pen may cause the computer scanner to read your answers incorrectly.

PRINT your name (last, first initial, middle initial), social security number, and dealer code in the spaces provided on the Scan-Tron® answer sheet. Then completely fill in the corresponding letter or number blocks in the columns below each character, as shown in the answer sheet example.

To take the test:

- **DO NOT MARK YOUR ANSWERS IN THIS BOOK.** Answer the questions by filling in the appropriate letter block next to the number for each question on the answer sheet.
- If you make a mistake, erase the mark as completely as possible.
- There is only one completely correct answer for each question.

After you have finished, follow the instructions for mailing in the answer sheet. **Good Luck!**

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1. Compressed natural gas (CNG) is ________.

A. a liquid, and flows just like gasoline

B. heavier than air, and seeks the ground when released

C. lighter than air, and dissipates upward when released

D. very similar to LP gas, only it comes from the ground

2. Which emission components found on gasoline vehicles are not found on comparable natural gas vehicles?

A. PCV system components

B. Evaporative emission system components

C. EGR system components

D. THERMAC system components

3. When the three fuel tanks are completely filled, they contain ________ psi.

A. 4800

B. 4200

C. 3600

D. 2800

4. The three fuel solenoid valves are located ________.

A. in the throttle body

B. at the rear of the fuel tanks

C. at the filler pipe

D. at the front of the fuel tanks

5. **The fuel solenoid valves are powered through the ________.**

   A. ignition switch

   B. starter circuit

   C. fuel pump relay

   D. fuel filler door

6. **The fuel solenoid valves control filling the tanks by ________.**

   A. closing off the rest of the fuel system when the ignition is off

   B. closing off the rest of the fuel system while the key is on

   C. shutting off the manual valve when the ignition is off

   D. shutting down the injector circuit switch

7. **The fuel pressure regulator reduces high side fuel pressure to about ________ psi at idle.**

   A. 50

   B. 145

   C. 175

   D. 200

8. **When the filler door is open, the fuel filler door switch keeps the vehicle from starting by ________.**

   A. causing an open in the starter power circuit

   B. shorting out the injector circuit

   C. blocking the fuel pump control relay power signal

   D. causing an open in the fuel pump control relay ground circuit

9. **Which statement below best describes the operation of the fuel gage?**

   A. The gage is mechanical and connected to the fuel system with steel tubing.

   B. The standard fuel gage is used with a transducer replacing the float unit.

   C. The fuel gage itself is a pressure-sensitive transducer connected to the system with steel tubing.

   D. The fuel gage electronically calculates miles to empty based on fuel volume.

10. **The knock sensor signal is not used on CNG vehicles because the ________.**

    A. revised injectors used with CNG would confuse the ECM

    B. high octane rating of CNG makes the knock sensor unnecessary.

    C. TECH 1 tester won't pick up the signal

    D. A.I.R. system is not needed

11. **The fuel tank safety relief valves will open if ________.**

    A. someone tries to fill the tanks to above 3,000 psi

    B. the injectors are malfunctioning

    C. the tanks become over pressurized or overheated

    D. the tanks become too rusted

12. **If there is no voltage on the power side of the fuel solenoid valve circuit when there should be, what should you check first?**

    A. The fuel filler

    B. The in-line fuse.

    C. The low pressure cut-off solenoid.

    D. The transducer.

13. If the vehicle starts and runs with the fuel filler door open, what should you check?

A. The in-line fuse.

B. The filler door switch and circuit wiring.

C. The starter circuit.

D. The ignition switch interlock circuit.

14. The manual, one quarter turn shut off valve is installed to ___________.

A. isolate one fuel tank from another

B. comply with NGV regulations

C. provide a vent when filling the tanks

D. aid in cold weather starting

15. The function of the low pressure cut-off solenoid is to _________.

A. allow the technician to manually shut off fuel pressure

B. cut power to the fuel solenoid valves if the regulator is malfunctioning

C. supply a voltage signal to the fuel gage when fuel pressure is low

D. shut off pressure in the low side of the system when the ignition is shut off

16. The fuel pressure test port on the natural gas vehicle is located _________.

A. on the regulator assembly

B. on the injector plate assembly

C. at the back of the far right fuel tank

D. at the manual shut-off valve

17. To avoid damage, the gage used for the fuel pressure test must be able to safely read pressure up to ________ psi.

A. 50

B. 100

C. 150

D. 200

18. What natural gas fuel system component(s) can be individually repaired?

A. Only the pressure regulator.

B. The fuel tank solenoid valves and the low pressure cut-off solenoid.

C. The manual shut-off valve and the tank safety relief valves.

D. None. All components must be replaced as whole units.

19. If one fuel tank solenoid remains closed during normal vehicle operation, the expected driving range will decrease by _______________.

A. one half

B. two thirds

C. one third

D. one fourth

20. All pipe-threaded components in the natural gas fuel system _________.

A. require new O-rings when replaced

B. require anaerobic pipe sealer when replaced

C. have quick-connect fittings

D. are on the low pressure side

COURSE SURVEY QUESTIONS

The following questions are not part of the test, but are for you to help us determine if programs like this one do what they're supposed to do. Your answers will help us in designing future courses that will continue to fit your needs.

1. How many years of dealership experience do you have? (If you have been at more than one, include all).

   [1] Less than one year

   [2] One to three years

   [3] Three to five years

   [4] More than five years

2. What were your reasons for taking this course?

   [1] Required for certification

   [2] Dealership requires it

   [3] To learn new skills I will need in my job

   [4] Just for general interest

3. How complete do you think this course was in covering the material? (Did the video and reference manual cover all necessary topics?)

Very Incomplete — **Very Complete**

1 2 3 4 5

4. Was the material presented in a clear and understandable manner?

Very Unclear — **Very Clear**

1 2 3 4 5

5. How much do you think taking this course will help you in your current job?

Not Much Help — **Considerable Help**

1 2 3 4 5

6. How satisfied were you with the video presentation in this course?

Not At All Satisfied				Completely Satisfied
1	2	3	4	5

7. How satisfied were you with the reference guide used for this course?

Not At All Satisfied				Completely Satisfied
1	2	3	4	5

8. Did the post-test questions address all of the key points in this course?

No, Most Key Points Not Covered				Yes, All Key Points Covered
1	2	3	4	5

9. Overall, how satisfied were you with this course?

Not At All Satisfied				Completely Satisfied
1	2	3	4	5

10. Would you like to see more courses like this in the future?

No, Not At All				Yes, Whenever Possible
1	2	3	4	5

NOTES

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